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THE LAW OF ERROR IN THE GREENWICH VARIATION OF LATITUDE OBSERVATIONS

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A classical remark made by Lippmann to Poincaré was that "Everybody believes in the law of errors, the experimenters because they think it is a mathematical theorem, the mathematicians because they think it is an experimental fact." The law spoken of is of course the normal or Gaussian law. If and only if it is true, the mean is the best estimate of the true value, and the mean square deviation provides the best estimate of the accuracy. It is therefore a crucial question in the combination of observations to know whether the normal law holds ; if it does not, other methods must be devised appropriate to the actual law. Karl Pearson actually showed in 1901 that some series of observations published in support of the normal law showed such departures from its predictions as would warrant its rejection. In a later paper he gave six series of observations made by himself and collaborators, in conditions resembling those of the determination of right ascension and declination with the transit circle, and found substantial departures from the normal law. I have recently rediscussed Pearson's data, and confirmed the main result. It is desirable, however, to know how general the results are, and whether any single law of error will apply to observational errors ; it seems clear that the same law will not apply to observational errors as to the yields in agricultural experiments (arising mainly from local variations in soil fertility), but it is not out of the question that there may be a general law of error, not the normal law, that will hold in observing conditions. In any case fuller information on the law of observational error is needed, and use of it should lead to improvement both in the accuracy of the results and in the validity of the estimates of uncertainty.

So far Pearson's Type VII has appeared to be satisfactory. These laws

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resemble the normal law in having a single peak and being infinitely extended, but for the same σ lie higher in the centre and on the tails, and lower for deviations near σ. In these laws the chance of an observation between x and $x+dx$ is ydx, where

$$y \propto \left\{1 + \frac{(x-a)^2}{2M\sigma^2}\right\}^{-m}. \tag{1}$$

If M/m tends to 1 when m tends to infinity this tends to the normal law with standard error σ; the most convenient form for actual fitting is

$$y = \frac{m!}{\{2\pi(m-\frac{1}{2})\}^{\frac{1}{2}}(m-\frac{1}{2})!\,\sigma}\left\{1 + \frac{m^2(x-a)^2}{2(m-\frac{1}{2})^3\sigma^2}\right\}^{-m}. \tag{2}$$

The expectation of $(x-a)^2$ is not equal to σ^2 with this definition; in fact, the law is significant when $m > \frac{1}{2}$, but the expectation of $(x-a)^2$ is infinite when $m \leqslant \frac{3}{2}$. Here

$$M = (m-\tfrac{1}{2})^3/m^2. \tag{3}$$

If we also write

$$\mu = 1/m, \tag{4}$$

μ may be regarded as an expression of the amount of departure from the normal law. The method of maximum likelihood is the best for estimating the unknowns a, σ and m; if L is the product of the values of y for the observed values of x, the best estimates are those that correspond to the maximum of L. When the law is taken in the form (2), it can be shown that the expectations of the coefficients of the cross terms (the term in the equation for σ proportional to the correction to m, and so on) are zero.* Thus these will in practice involve only random error, and to neglect them will introduce only errors proportional to $1/n$, where n is the number of observations, while the inevitable uncertainty is of order $1/\sqrt{n}$. Also the error in any parameter, at any stage in the solution, will produce only a second order change in the estimate of another, and it is possible to proceed rapidly by iteration, the errors being squared at each step. The equations to determine a, σ and m then reduce to

$$-\frac{\partial}{\partial a}\log L = \frac{m}{M\sigma^2}\sum\frac{x-a}{1+(x-a)^2/2M\sigma^2} = 0, \tag{5}$$

$$-\frac{\partial}{\partial \sigma}\log L = \frac{n}{\sigma} - \frac{m}{M\sigma^3}\sum\frac{(x-a)^2}{1+(x-a)^2/2M\sigma^2} = 0, \tag{6}$$

$$-\frac{\partial}{\partial \mu}\log L = nm^2\left(\frac{d}{dm}\log m! - \frac{d}{dm}\log(m-\tfrac{1}{2})! - \frac{1}{2(m-\frac{1}{2})}\right)$$
$$-\sum m^2\log\left(1+\frac{(x-a)^2}{2M\sigma^2}\right) + \sum\frac{m^4(m+1)(x-a)^2}{2\sigma^2(m-\frac{1}{2})^4\{1+(x-a)^2/2M\sigma^2\}} = 0. \tag{7}$$

It is best to regard the last equation as fundamentally an equation for μ rather than m, because when m is large, corresponding to small departures

* Jeffreys, *Phil. Trans.*, A, 237, 231–271, 1938.

from the normal law, the posterior probability of μ is nearly normally distributed, which is not true of m, and because the function is easily interpolated with μ as argument, but not with m. The derivatives of $\log m!$ are given in the British Association tables, but unfortunately not in the range between $m = 1{\cdot}0$ and $10{\cdot}0$, which is the range required; they can, however, be derived from those between 0 and 1 by the induction formula.

The solution is to be found by first taking approximate values of two of the parameters and substituting trial values of the other in the equation to determine it. The next approximation to this is then got by interpolation. Further, its standard error will be given by

$$\frac{1}{\sigma^2(\mu)} = -\frac{\partial^2}{\partial \mu^2} \log L \tag{8}$$

and analogous relations; the right side is found in the process of interpolation by numerical differentiation. Alternatively, there are convenient approximate formulæ for the standard errors of a and σ, but not for that of μ.

Pearson's method of fitting * was to compute the mean values of x, x^2, x^3 and x^4 for the observed values and choose the values of the parameters that would make the expectations of these means agree with the observed values. (With a symmetrical law such as Type VII the need for x^3 does not arise.) If we denote the means of $(x-a)^2$ and $(x-a)^4$ by μ_2 and μ_4, and put

$$\mu_4/\mu_2{}^2 = \beta_2, \tag{9}$$

then the expectations of μ_2 and μ_4 are related by

$$\frac{\mu_4}{\mu_2{}^2} = 3\frac{m - 1{\cdot}5}{m - 2{\cdot}5}, \tag{10}$$

whence

$$3\frac{m - 1{\cdot}5}{m - 2{\cdot}5} = \beta_2 \tag{11}$$

provides an estimate of m. This is useful to provide a preliminary estimate, but the method is known to be inefficient for large departures from normality. In particular the expectation of $(x-a)^4$ is infinite for $m \leqslant 2{\cdot}5$, but the mean fourth power of the observed values is always finite, whatever the law is. Hence even if m is really below $2{\cdot}5$ the method of moments will always say that it is greater than $2{\cdot}5$.

Dr. H. R. Hulme has kindly provided me with a list of the residuals of the Greenwich variation of latitude observations, divided into two periods containing 4540 and 5014 observations respectively.† These afford the largest quantity of information yet available for estimating departures from the normal law, and have the advantage over Pearson's data that they are really observations designed to measure something, not only to study the

* Described in Brunt's *Combination of Observations*, Chapter 9.

† Cf. *M.N.*, **99**, 642, 1939.

observations themselves, and therefore may be more representative of the usual conditions of scientific work. The first step is simply to compute the means of x, x^2 and x^4. The first was practically zero, and a will be neglected in the process of estimating m. The second and fourth moments gave

	μ_2	β_2	m
1927–31	5·174	7·14	3·22
1932–36	6·810	9·00	3·00

The unit is $0''{\cdot}1$.

Now μ_2 is the estimate of σ^2 on the hypothesis that m is infinite. But the estimates of m suggested by the moments are so little above 2·5 that it is possible that m is really below 2·5 and that the method of moments is quite useless for determining it. As a second approximation I determined σ^2 from (6) on the hypothesis that $m = 3$. The first series now gave $\sigma^2 = 4{\cdot}609$. With this closer estimate of σ^2, for different values of m, I get the following :—

m	μ	$\partial(\log L)/\partial\mu$	f_1
3·0	0·3333	+ 88	
			−2444
2·5	0·4000	− 75	
			−2410
2·0	0·5000	−316	

f_1 is the first divided difference against μ. Then by interpolation

$$\mu = 0{\cdot}369 \pm 0{\cdot}020,$$

the uncertainty being got from (8). Limits for m corresponding to the standard error are 2·86 and 2·57.

Since the error of σ^2 is proportional to the square of that of μ we have the equations for σ^2:

$$\sigma^2 = 5{\cdot}174 + (0{\cdot}369)^2 A,$$
$$\sigma^2 = 4{\cdot}609 + (0{\cdot}036)^2 A,$$

whence

$$\sigma^2 = 4{\cdot}603 \; ; \quad \sigma = 2{\cdot}146 \pm 0{\cdot}029,$$

the uncertainty of σ being got by using (6) on p. 269 of my paper, namely

$$\sigma^2(\sigma) = \frac{(m+1)\sigma^2}{2n(m-\frac{1}{2})}.$$

Further approximation is unnecessary.

For the second series, with $m = 3$, I got the second approximation

$$\sigma^2 = 5{\cdot}203,$$

and using this the equations to determine m are

m	μ	$\partial(\log L)/\partial\mu$	f_1
3·0	0·3333	+386	
			−3730
2·5	0·4000	+137	
			−2920
2·0	0·5000	−155	

whence, using the second difference, $\mu = 0{\cdot}443 \pm 0{\cdot}018$; $m = 2{\cdot}17$ to $2{\cdot}35$. Extrapolating for σ^2, we get

$$\sigma^2 = 5{\cdot}096 \; ; \quad \sigma = 2{\cdot}257 \pm 0{\cdot}031.$$

For convenience in the arithmetic the data were grouped in intervals of 0″·1, Hulme's interval being 0″·01. Thus the grouping interval is nearly half the standard errors and some correction should strictly be made for it. For the normal law the rule is that σ^2 should be reduced by $\frac{1}{12}h^2$, where h is the grouping interval. The modification necessary for large departures from the normal law is not known (short of not grouping the data at all), but if this correction is applied to the above values of σ^2 they lead respectively to $\sigma = 2{\cdot}126$ and $2{\cdot}239$, with the previous standard errors. The changes are less than the standard errors, but certainly have the right sign. If they are applied the corresponding μ should be slightly increased to give a representation of the outlying observations, and therefore the estimated departure from the normal law will be increased.

In my study of the observations given by Pearson, in sets of about 500, I found departures from the normal law, and also signs of correlation between the errors of neighbouring observations. The departure from normality and the degree of internal correlation were highly correlated, and suggested, by extrapolation, that if the condition that the errors were truly independent was ever satisfied, m would be about 3·5. The comparison can be shown as follows. r is a number expressing the amount of internal correlation, judged from the comparison of the variation of the means of about 25 consecutive observations with the variation of the residuals in each series as a whole. We may fit a linear form

$$\mu = a + br$$

by least squares, treating all determinations as of equal weight. Negative μ corresponds to Type II laws, which depart from the normal in the opposite sense to Type VII.

μ	r	μ calc.	$O-C$
+0·230	+0·16	+0·173	+0·057
+0·163	+0·24	+0·123	+0·040
+0·111	+0·23	+0·129	−0·018
+0·04	+0·57	−0·083	+0·123
−0·080	+0·32	+0·073	−0·153
−0·225	+0·72	−0·176	−0·049

The solution is $a = +0{\cdot}273 \pm 0{\cdot}093$; $b = -0{\cdot}62 \pm 0{\cdot}22$. The former value, corresponding to $m = 3{\cdot}66$, with a range from 2·73 to 5·53, would be appropriate to observations free from internal correlation. The first value of μ as it stands has a standard error of 0·057, and would correspond to m from 3·5 to 5·8. On the other hand, the determinations are likely to be better when r is small than when it is large. With weights proportional to $1/r$ the results are $a = +0{\cdot}311 \pm 0{\cdot}099$, $b = -0{\cdot}720 \pm 0{\cdot}65$. The corresponding m is 3·22, standard range 2·44 to 4·74. There appears to be a numerical mistake in the unnecessarily complicated procedure adopted in my previous paper at this point (p. 267). The first pair of estimates are the better, since the second pair suggest that b is doubtfully relevant ; but this would mean that the correlation between μ and r is in serious doubt. Correcting the previous arithmetic, I get −0·82 for the correlation and for Fisher's z the value $-1{\cdot}16 \pm 0{\cdot}50$, which looks trustworthy.

Collecting the results we have for m and μ :

	m	μ
Pearson	2·7 to 5·5	0·180 to 0·366
Greenwich 1927–31	2·6 to 2·9	0·349 to 0·389
Greenwich 1932–36	2·2 to 2·35	0·425 to 0·461

There is an appreciable difference between the two Greenwich series ; the range corresponding to the standard error from Pearson's data overlaps the first but not the second. There is therefore probably a real difference in the appropriate values of m ; but this has an obvious explanation. The Greenwich observations were made by several observers in different conditions of observation. This would naturally lead to a variation of accuracy ; but if several homogeneous series, even of different accuracy, derived from the normal law, were combined and treated together the result would give a positive μ.* The values found for μ from the Greenwich observations are therefore likely to be too high for uniform observing conditions. The most probable value from Pearson's data is 0·273 ; this is extrapolated from one of 0·230, which is presumably too low on account of the empirical result that the tendency of internal correlation of the errors was found to be to decrease μ, and some internal correlation was present in all his series. Thus if there is a single suitable value of μ for uniform observing conditions, with independence of the errors, Pearson's data show that it is likely to be more than 0·23, very likely to be more than 0·18, and the Greenwich ones that it is likely to be less than 0·36 ; in other words, m is probably between 3 and 5.

This type of difficulty is likely to remain serious. Less than about 500 observations are not usually enough to determine μ with a standard error under 0·05, and $0{\cdot}25 \pm 0{\cdot}05$ corresponds to a range of m from 3·3 to 5 even if departures beyond the standard error do not occur. But with longer series it becomes increasingly probable that the conditions of observation will not remain uniform. Indeed, as Hulme points out to me, it is difficult to produce an applicable criterion for a homogeneous series. If we try to state conditions such that we can be sure that the same law of error holds for every observation we are liable to find that no homogeneous series contains more than one observation. Fortunately, however, an accurate determination of m is not needed for the practical determination of a and σ, which are what we usually want most to know, because an error in m produces only second order errors in them. In a forthcoming book † I have given a table of weights for fitting a law with index 4, which should be good enough for most practical purposes. To adopt this as a regular procedure, determining a and σ from (5) and (6), would avoid the present perpetual difficulty of deciding whether any observations should be rejected, and if so, which. This is most important in special investigations where there may be 20 relevant observations or less. With 100 or more, even if the index is 4, the loss of accuracy due to assuming the normal law may not be great. But if 20 observations happen to contain one or two from the tail of the

* But if there was any upper limit to their standard errors they could never give an infinite fourth moment.

† *Theory of Probability*, p. 254.

distribution their effect may easily be as large as the apparent standard error of the mean, and the best treatment is to use the information about the law of error suggested by longer series made under as similar conditions as possible. With a Type VII law there is no need to reject any observations, though it may be permissible to reject those recorded as under suspicion when they are made ; a large deviation does not produce a large displacement of the estimate of a or of σ. It would be desirable, however, to classify data in groups of 100 or so and make separate determinations of σ from them whenever this is possible, in order to replace spurious increase of μ due to variation of observing conditions by more detailed information about the accuracy.

The second of the Greenwich series is actually in the range where the estimated standard error, according to the method of moments, is meaningless. These rules suppose first that the law of error is known and that a set of observations is taken at random. The mean square deviation is then to be taken from the sample ; the uncertainty of this is measured by the expectation of the square of its difference from the expected value. In this sense the latter expectation involves the fourth moment of the law and therefore is infinite if m is less than 2·5. The expectation of the largest residual increases so rapidly with the number of observations that the mean fourth power will be expected to increase with n beyond any finite limit. In the first of these series the largest absolute deviation is at 7·3, in the second at 10·7 times the final σ. But with an efficient method of fitting the information contained in these large deviations goes mostly into the determination of m and hardly affects σ. The effect on a is, of course still smaller. The gaps between consecutive residuals naturally become wider the further out we go, but not in such a way as to suggest that any observation should be definitely rejected.

Summary

The two series of residuals of the Greenwich variation of latitude observations agree with laws of Pearson's Type VII with indices of about 2·7 and 2·2. This is a very large departure from the normal law of error, but has probably been increased by variation of the observing conditions. Comparison with the data given by Pearson suggests that the index for homogeneous observations is likely to be between 3 and 5, and that there would be advantages in using a law with index 4 in the reduction of observations.

THE URSA MAJOR CLUSTER (SECOND PAPER)

W. M. Smart, M.A., D.Sc.

1. In a recent paper * (referred to later as Paper A) I investigated the claims of 34 stars, taken from Rasmuson's † and Plummer's ‡ lists, to be regarded as members of the Ursa Major Cluster, and it was concluded that, of these stars, 23 are cluster-stars, with 5 doubtful. Since the publication of the paper, Professor J. J. Nassau has drawn my attention to a paper § (referred to, later, as Paper B) by himself and L. G. Henyey, in which 101 additional stars are investigated. As our methods of procedure are entirely different the present work has been undertaken with the object of submitting each star in the new list to the same criteria for membership of the cluster as applied in Paper A.

The method adopted by Nassau and Henyey in Paper B may first be briefly described. With the values of the co-ordinates of the convergent point and the linear velocity of the cluster relative to the Sun assumed (Rasmuson's values were used), the computed radial velocity, ρ, of each star and the linear velocity components P and Q, corresponding to the usual proper motion components μ_δ and $\mu_\alpha \cos\delta$ respectively, can be readily found; actually, the values of ρ and P were ingeniously obtained from a stereographic projection of the celestial sphere, the primary function of which was the detection of possible members of the cluster. Thus ρ, P and Q depend only on the kinematical characteristics of the cluster. Let ρ_0, P_0 and Q_0 be the values of the linear components of velocity, derived directly from observations; ρ_0 is the observed radial velocity; P_0 and Q_0 are calculated using the observed values of the parallax and of the proper motion components, all the observed quantities being taken from Schlesinger's *Bright Star Catalogue* (*B.S.C.*). The sums of the squares of the residuals according to the formula

$$R^2 = (\rho - \rho_0)^2 + (P - P_0)^2 + (Q - Q_0)^2$$

were then calculated. The criterion used to determine membership of the cluster was simply that R should be numerically less than 9·5 km./sec., a value suggested by the cluster-stars in Rasmuson's list. There is no doubt that this criterion gathers in its net all *possible* members of the cluster, but it does not follow, without further investigation, that all such stars are necessarily cluster-stars.

The most certain data we have of the Ursa Major Cluster are (i) the

* *M.N.*, **99**, 441, 1939.

† *Lund Medd.*, Ser. II, No. 26, 1921.

‡ *M.N.*, **76**, 134, 1916.

§ *Ap. J.*, **80**, 282, 1934. See also a further paper by Nassau, *A.J.*, No. 1038, 1935.

co-ordinates of the convergent point and (ii) the linear velocity of the cluster relative to the Sun ; with this in mind, the procedure adopted in Paper A was based on a direct comparison of the position angles of the proper motions, the radial velocities and the parallaxes (all calculated from the known kinematical characteristics of the cluster) with the corresponding observed values.

A similar procedure is adopted in the present paper.

2. Table I gives some of the details of the stars considered, the serial numbers in the first column following the numbers in Paper A. The star No. 35 is Gr. 1970 which is the subject of a note in *M.N.*, 99, 700, 1939 ; the remaining stars are from the list in Paper B, omitting those stars common to Papers A and B. To facilitate comparison with the data of Paper B, the star's number in the *Bright Star Catalogue* is given in the second column. The number in the *General Catalogue* is given in the third column, and in the fifth and sixth columns the values of $\mu_\alpha \cos\delta$ and μ_δ, derived from the same source, are entered, with their probable errors in the last two columns.

With the notation of Paper A, a single asterisk attached to the serial number signifies that the star concerned is adjudged, according to the several criteria considered later, *not* to be a member of the cluster ; a double asterisk signifies that membership of the cluster is regarded as doubtful. It may be noted that a large proportion of the stars are in this latter category ; in many instances it seemed inadvisable to throw out such stars prematurely without giving future observations a chance of deciding the issue with greater certainty.

The remaining stars (those without asterisks, single or double) are considered to be members of the cluster.

3. The second and third columns of Table II contain the position angles of the proper motions as derived from the observed components of proper motion in Table I and as calculated from the known position of the convergent point (R.A., 307°·5 ; Dec., −39°·3) derived in Paper A ; the fourth column gives the corresponding differences. In the fifth column are tabulated the probable errors of the observed position angles calculated by means of the probable errors of $\mu_\alpha \cos\delta$ and μ_δ given in Table I ; for simplicity it was assumed for any given star that the probable errors in the two co-ordinates are the same and equal to the mean of the tabulated values. In Paper A the largest discrepancy between the observed and calculated position angles is 6° ; in the present paper the criterion based on the position angles is somewhat relaxed, due consideration being paid to the probable errors in the fifth column of Table II. It is to be realised, however, that the tabulated probable errors take no cognisance of possible systematic errors in the proper motions. For stars with total proper motions of the order of 0″·1 or 0″·2, such systematic errors are hardly likely to produce errors of more than a degree or two in the observed position angles. On the other hand, the effect of systematic errors for stars with total proper motions of the order of 0″·02 or 0″·03 must be very much larger ; for this reason, it seems advisable, so far as this criterion is

No.	B.S.	G.C.	Star	$\mu_a \cos\delta$ (Unit : 0″·001)	μ_δ (Unit : 0″·001)	P.E. $\mu_a \cos\delta$ (Unit : 0″·0001)	P.E. μ_δ (Unit : 0″·0001)
35	...	17919	Gr. 1970	+110	− 35	± 38	± 33
36*	68	362	σ And	− 65	− 36	19	16
37**	180	823	μ Phe	− 26	0	35	29
38*	196	894	P.G.C. 154	− 27	+ 5	28	23
39**	378	1566	89 Psc	− 52	− 19	13	12
40	497	2085	π Scl	− 58	− 19	35	32
41**	569	2366	λ Ari	− 91	− 12	15	12
42	647	2668	...	− 65	− 58	41	28
43**	797	3260	85 Cet	− 25	− 19	23	21
44*	872	3463	ν Hyi	− 32	− 19	38	34
45*	892	3580	...	− 30	− 52	49	37
46**	1002	4004	32 Per	− 57	− 1	23	19
47*	1143	4455	h Eri	− 93	− 71	28	23
48	1195	4624	g Eri	− 51	− 49	25	24
49**	1327	5199	...	− 27	− 2	30	20
50*	1381	5325	66 Tau	− 15	− 6	24	21
51**	1448	5570	...	− 19	− 10	40	38
52**	1872	6896	38 Ori	− 31	− 18	25	22
53	1982	7196	...	−305	−355	32	34
54**	1995	7277	τ Aur	− 22	− 25	19	17
55*	2029	7404	ξ Aur	− 8	+ 17	25	16
56	2047	7419	χ Ori	−184	− 87	14	11
57	2296	8214	δ Col	− 30	− 56	29	23
58*	2487	8858	57 Aur	− 1	+ 3	23	18
59*	2585	9113	16 Lyn	− 20	− 4	23	17
60**	2753	9677	64 Aur	− 14	+ 10	13	12
61	2763	9701	λ Gem	− 43	− 43	9	9
62*	3132	10871	4 Cnc	− 18	+ 16	28	26
63*	3221	11199	56 Cam	− 12	+ 4	29	24
64**	3391	11817	3 UMa	− 24	+ 85	18	17
65*	3441	11959	9 Hya	− 3	− 94	33	28
66*	3450	11983	45 Cnc	− 1	− 2	24	20
67**	3485	12069	δ Vel	+ 17	− 84	19	20
68	3512	12195	...	+ 5	− 49	45	37
69**	3572	12406	α Cnc	+ 35	− 37	8	8
70*	3587	12456	66 Cnc	− 3	− 3	24	20
71**	3595	12496	ν Cnc	− 1	− 9	17	16
72*	3676	12799	...	+ 21	+ 8	25	21
73*	3800	13203	10 LMi	+ 10	− 27	14	12
74*	3894	13559	φ UMa	− 3	+ 14	15	14
75**	3903	13570	υ Hya	+ 19	− 29	20	18
76**	3974	13896	21 LMi	+ 53	− 2	20	16
77	3998	13999	34 Leo	+ 39	− 42	19	21
78**	4031	14107	ζ Leo	+ 19	− 13	10	10
79*	4101	14361	45 Leo	+ 6	− 3	20	17
80*	4216	14842	μ Vel	+ 64	− 56	24	23
81**	4299	15151	61 Leo	+ 15	− 37	21	18
82**	4418	15729	τ Leo	+ 18	− 17	9	9
83	4514	16112	ζ Crt	+ 34	− 38	14	14
84*	4716	16906	5 CVn	+ 11	+ 7	20	17
85	4842	17339	ι Cru	+101	− 75	53	34

No.	B.S.	G.C.	Star	$\mu_\alpha \cos\delta$ (Unit : 0″·001)	μ_δ (Unit : 0″·001)	P.E. $\mu_\alpha \cos\delta$ (Unit : 0″·0001)	P.E. μ_δ (Unit : 0″·0001)
86*	4859	17377	...	+ 17	− 6	± 36	± 30
87	4865	17401	29 Com	+ 32	− 32	22	18
88*	4955	17794	49 Vir	+ 15	− 13	18	14
89*	5009	17932	...	− 8	+ 8	16	18
90	5214	18721	...	+ 29	− 19	30	27
91*	5329	19207	κ^2 Boo	+ 63	− 10	20	15
92**	5365	19319	18 Boo	+104	− 37	22	19
93**	5373	19341	...	+ 21	− 20	29	23
94**	5727–8	20696	η CrB	+133	−195	13	12
95**	5840	21089	19 Ser	+ 26	− 22	22	21
96	5843	21105	χ Ser	+ 38	− 20	26	21
97**	5886	21246	...	+ 37	− 61	15	14
98*	5888	21280	ω Ser	+ 27	− 56	23	21
99**	6110	22040	23 Her	+ 13	− 15	21	16
100*	6117	22090	ω Her	+ 41	− 65	15	14
101*	6146	22172	g Her	+ 25	− 8	19	15
102**	6254	22662	52 Her	+ 23	− 62	21	17
103**	6292	22810	56 Her	+ 11	− 26	24	21
104*	6481	23556	...	+ 6	− 32	34	27
105**	6618	24093	...	+ 19	− 20	30	28
106**	6917	25165	...	+ 13	− 25	38	32
107	6993	25456	...	+ 8	− 24	34	31
108**	7267	26374	...	− 32	− 99	65	73
109**	7312	26484	59 Dra	+ 47	−121	20	17
110**	7400	26900	35 Aql	− 7	− 34	21	22
111	7451	27068	...	+ 25	−192	26	20
112**	7545	27367	...	+ 13	− 22	32	30
113*	7555	27453	...	+ 1	− 12	26	20
114**	7781	28258	...	− 9	− 25	30	19
115*	7822	28481	ρ Cap	− 16	− 23	9	10
116*	7826	28467	40 Cyg	− 28	− 71	24	18
117**	7928	28873	δ Del	− 25	− 48	11	12
118**	8039	29331	γ Mic	+ 8	+ 5	28	26
119	8170	29889	...	− 23	−207	90	83
120*	8207	30027	35 Cap	− 28	− 28	21	28
121**	8252	30207	ρ Cyg	− 24	− 91	18	13
122**	8263	30265	...	− 21	− 20	28	22
123**	8287	30377	26 Aqr	− 4	− 4	22	19
124**	8407	30848	...	− 19	− 33	32	23
125**	8410	30872	32 Aqr	− 21	− 48	20	20
126**	8454	31016	π Peg	− 15	− 22	12	12
127*	8488	31138	μ^2 Gru	− 11	− 11	39	36
128**	8573	31440	σ Aqr	− 1	− 28	9	9
129**	8641	31674	o Peg	− 8	− 26	23	17
130*	8649	31708	66 Aqr	− 30	− 25	26	25
131**	8694	31857	ι Cep	− 67	−122	8	8
132	8695	31895	γ PsA	− 35	− 24	24	24
133*	8709	31943	δ Aqr	− 42	− 21	9	10
134**	8821	32267	58 Peg	− 18	− 8	24	16
135**	8906	32594	99 Aqr	− 55	− 56	19	20
136*	9064	33230	ψ Peg	− 39	− 29	18	15

Position Angles of the Proper Motions

No.	Obs.	Cal.	Obs. – Cal.	P.E.	No.	Obs.	Cal.	Obs. – Cal.	P.E.
	°	°	°	°		°	°	°	°
35	107·6	99·9	+ 7·7	± 1·6	86	109·4	88·6	+ 20·8	± 10·5
36	241·0	220·1	+ 20·9	1·3	87	135·0	127·3	+ 7·7	2·5
37	270·0	256·2	+ 13·8	6·4	88	130·9	133·0	− 2·1	4·6
38	280·5	226·7	+ 53·8	5·3	89	315·0	78·1	−123·1	8·8
39	250·0	228·6	+ 21·4	1·2	90	122·3	120·0	+ 2·3	4·6
40	251·8	239·6	+ 12·2	3·2	91	99·0	113·9	− 14·9	1·6
41	262·5	230·6	+ 31·9	0·8	92	109·6	128·1	− 18·5	1·1
42	228·3	238·2	− 9·9	2·2	93	133·6	121·1	+ 12·5	5·1
43	232·8	231·4	+ 1·4	4·1	94	145·7	130·0	+ 15·7	0·3
44	239·3	253·5	− 14·2	5·6	95	130·2	132·3	− 2·1	3·7
45	210·0	230·3	− 20·3	4·1	96	117·8	132·2	− 14·4	3·2
46	269·0	245·3	+ 23·7	2·1	97	148·8	125·1	+ 23·7	1·2
47	232·6	228·8	+ 3·8	1·2	98	154·3	131·4	+ 22·9	2·0
48	226·1	227·8	− 1·7	2·0	99	139·1	136·7	+ 2·4	5·4
49	265·8	273·7	− 7·9	5·3	100	147·7	135·9	+ 11·8	1·1
50	248·2	230·4	+ 17·8	8·2	101	108·5	137·0	− 28·5	3·7
51	242·2	228·2	+ 14·0	10·6	102	159·6	139·7	+ 19·9	1·7
52	239·9	222·4	+ 17·5	3·7	103	157·1	140·7	+ 16·4	4·7
53	220·7	212·7	+ 8·0	0·4	104	169·4	143·2	+ 26·2	5·6
54	221·4	256·3	− 34·9	3·1	105	136·5	148·5	− 12·0	5·9
55	334·8	285·1	+ 49·7	6·0	106	152·5	155·3	− 2·8	7·2
56	244·7	231·9	+ 12·8	0·4	107	163·7	149·4	+ 14·3	7·6
57	208·2	205·1	+ 3·1	2·3	108	197·9	161·2	+ 36·7	3·8
58	341·6	286·7	+ 54·9	40·1	109	158·8	163·0	− 4·2	0·8
59	258·6	279·8	− 21·2	5·7	110	191·6	162·1	+ 29·5	3·6
60	305·5	270·4	+ 35·1	4·4	111	172·6	169·0	+ 3·6	0·7
61	225·1	212·5	+ 12·6	0·8	112	149·4	170·6	− 21·2	6·8
62	311·6	203·8	+107·8	6·1	113	175·2	172·0	+ 3·2	11·0
63	288·4	350·1	− 61·7	12·3	114	199·8	177·6	+ 22·2	5·3
64	344·2	2·8	− 18·6	1·2	115	214·8	177·9	+ 36·9	2·0
65	181·8	179·0	+ 2·8	1·9	116	201·5	179·2	+ 22·3	1·6
66	206·6	175·1	+ 31·5	63·0	117	207·5	182·6	+ 24·9	1·3
67	168·6	177·4	− 8·8	1·3	118	58·0	218·1	−160·1	17·2
68	174·2	176·4	− 2·2	4·8	119	186·4	189·5	− 3·1	2·4
69	136·6	169·0	− 32·4	0·9	120	225·0	210·1	+ 14·9	3·6
70	220·1	139·6	+ 80·5	31·5	121	194·8	191·9	+ 2·9	1·0
71	186·3	158·5	+ 27·8	10·8	122	226·4	199·1	+ 27·3	5·1
72	69·2	50·3	+ 18·9	6·0	123	225·0	199·6	+ 25·4	20·0
73	159·6	107·0	+ 52·6	2·6	124	209·9	197·4	+ 12·5	4·2
74	347·9	49·7	− 61·8	6·1	125	203·6	206·1	− 2·5	2·2
75	146·8	161·8	− 15·0	3·1	126	214·3	199·3	+ 15·0	2·5
76	92·2	108·6	− 16·4	1·9	127	225·0	268·9	− 43·9	13·6
77	137·1	144·2	− 7·1	2·0	128	182·1	217·6	− 35·5	1·8
78	124·4	131·6	− 7·2	2·5	129	197·1	205·5	− 8·4	4·2
79	116·6	143·7	− 27·1	15·5	130	230·2	227·3	+ 2·9	3·8
80	131·2	154·5	− 23·3	1·6	131	208·8	207·5	+ 1·3	0·3
81	157·9	144·4	+ 13·5	2·9	132	235·6	247·5	− 11·9	3·3
82	133·4	138·4	− 5·0	2·1	133	243·4	226·0	+ 17·4	1·2
83	138·0	142·9	− 4·9	1·6	134	244·0	214·1	+ 29·9	5·7
84	57·5	95·9	− 38·4	8·4	135	224·5	233·5	− 9·0	1·5
85	126·6	131·7	− 5·1	2·1	136	233·4	217·8	+ 15·6	2·0

concerned, not to reject off-hand many stars in the list as potential members of the cluster when the differences in the fifth column of Table II are considerably greater than those given in Paper A.

4. We consider now the criterion depending on the agreement, or lack of agreement, between the observed and calculated radial velocities.

The second column of Table III gives the H.D. numbers of the stars, and the third column gives the angular distances, λ, from the convergent point. The fourth column contains the observed radial velocities taken from Moore's catalogue * ; the final column gives the probable errors of these velocities taken from the same source, with indications as to the variability—established or suspected—of the radial velocities. In the fifth column are found the values of the radial velocity, ρ, calculated from the formula

$$\rho = V \cos \lambda,$$

V having the value of 19·1 km./sec. obtained in Paper A. The sixth column gives the differences between the observed and calculated radial velocities.

The application of the radial velocity criterion rules out at once a considerable number of stars from membership of the cluster ; for example, star No. 65 with a difference of 8·9 km./sec. between the observed and calculated radial velocity—the former determined apparently with considerable accuracy—can hardly be regarded as other than a field star, however satisfactory the application of the other criteria may be.

5. The third criterion to be applied is based on the accordance, or otherwise, between the values of the observed parallax (trigonometric or spectroscopic) and the calculated parallax, p, obtained from the formula

$$p = \frac{4{\cdot}74\mu}{V \sin \lambda},$$

where μ is the total proper motion.

The second column of Table IV contains the values of μ and in the third column are reproduced, for convenience, the values of λ. The next three columns give the values of the calculated, trigonometric and spectroscopic parallaxes in order ; for the two latter categories the entries are from Schlesinger's *General Catalogue of Stellar Parallaxes* (1935), with the exception of those values in the spectroscopic column, marked with an asterisk, which were taken from the *Bright Star Catalogue* (in the absence of any information to the contrary, these latter are presumed to be spectroscopic determinations, although this identification is not certain in all cases). I have not thought it necessary to give the probable errors of the trigonometric parallaxes—these may be presumed to be $\pm$ 0″·010 at most. With comparatively few exceptions there is satisfactory agreement between the calculated parallax and either the trigonometric or spectroscopic parallax ; thus, the application of the parallax criterion leaves the bulk of the stars as possible members of the cluster.

Of the stars finally assigned to the cluster there are 10 with known

* *Lick Publ.*, **18**, 1932 ; the second value for star No. 35 is by J. S. Plaskett.

No.	H.D.	λ	Obs.	Cal.	Obs.-Cal.	P.E.
		°				
35	115043	132·3	{ − 7·9 −11·1	−12·8	{ +4·9 +1·7	± 0·9 }
36	1404	91·8	− 9·9	− 0·6	−9·3	2·0 Var.
37	3919	45·0	+16·5	+13·5	+3·0	0·1
38	4222	108·5	− 8·3	− 6·1	−2·2	1·1
39	7804	77·8	+ 4·8	+ 4·0	+0·8	1·9 Var. ?
40	10537	61·1	+10·4	+ 9·3	+1·1	0·9 Var. ?
41	11973	98·2	+ 0·1	− 2·7	+2·8	1·1
42	13594	114·9	− 8·3	− 8·1	−0·2	0·8
43	16861	98·5	+ 4·7	− 2·8	+7·5	2·2
44	18293	53·5	+ 4·7	+11·4	−6·7	0·4
45	18543	93·1	− 7·2	− 1·0	−6·2	0·4
46	20677	123·4	− 6·6	−10·5	+3·9	2·4 Var.
47	23319	78·6	+ 9·9	+ 3·8	+6·1	0·3
48	24160	80·3	+ 2·0	+ 3·3	−1·3	0·5
49	27022	136·0	−18·5	−13·7	−4·8	0·4
50	27820	117·3	− 1·5	− 8·8	+7·3	1·1
51	28978	116·7	− 7·2	− 8·6	+1·4	1·1
52	36777	126·2	− 9	−11·3	+2·3	4 Var. ?
53	38392	106·9	− 9·7	− 5·6	−4·1	0·8
54	38656	148·1	−19·5	−16·2	−3·3	0·4
55	39283	149·1	−12·5	−16·4	+3·9	0·7
56	39587	141·1	−13·6	−14·8	+1·2	0·2
57	44762	101·3	− 2·4	− 3·7	+1·3	...
58	48781	158·8	− 9·0	−17·8	+8·8	0·6
59	50973	161·3	− 9·1	−18·1	+9·0	2·3
60	56221	165·5	−15·0	−18·5	+3·5	2·1
61	56537	152·0	−13·8	−16·9	+3·1	1·9
62	65856	164·4	...	−18·4	...	...
63	68457	158·6	−16·2	−17·8	+1·6	1·0
64	72905	154·1	−11·2	−17·2	+6·0	0·3
65	74137	124·9	− 2·1	−11·0	+8·9	0·6
66	74228	153·5	−18·8	−17·1	−1·7	1·2
67	74956	86·1	+ 2·2	+ 1·3	+0·9	1·6
68	75605	108·0	− 7·8	− 5·9	−1·9	0·7 Var.
69	76756	152·1	−1 5	−16·9	+3·4	0·5
70	77104	171·0	−1 .	−18·9	+6·1	2·0
71	77350	164·0	−16·3	−18·4	+2·1	1·0 Var. ?
72	79763	168·8	−12·1	−18·7	+6·6	...
73	82635	167·5	−11·7	−18·6	+6·9	0·3
74	85235	160·0	−12·2	−18·0	+5·8	0·6
75	85444	123·0	−14·5	−10·4	−4·1	0·3
76	87696	161·0	−16·8	−18·1	+1·3	1·7
77	88355	146·3	−16·5	−15·9	−0·6	0·7
78	89025	153·0	−18·7	−17·0	−1·7	1·5 Var.
79	90569	141·1	−10·0	−14·8	+4·8	1·8
80	93497	86·7	+ 6·9	+ 1·1	+5·8	0·1
81	95578	126·2	−13·1	−11·3	−1·8	0·6 Var.
82	99648	126·5	− 9·1	−11·3	+2·2	0·2
83	102070	107·2	− 4·6	− 5·6	+1·0	0·4
84	107950	138·8	−13·0	−14·4	+1·4	0·3 Var. ?
85	110829	67·6	+ 8·9	+ 7·3	+1·6	0·3

No.	H.D.	λ	Obs.	Cal.	Obs.-Cal.	P.E.
86	111270	136°0	−18·0	−13·7	−4·3	± 0·3
87	111397	119·0	− 7·0	− 9·3	+2·3	1·4
88	114038	99·2	− 9·1	− 3·1	−6·0	0·4
89	115337	131·8	−10·5	−12·8	+2·3	1·9
90	120818	118·5	−12·3	− 9·1	−3·2	1·6
91	124675	122·5	−14·9	−10·3	−4·6	0·2 Var.
92	125451	100·8	− 1·9	− 3·6	+1·7	0·6
93	125642	115·5	−12·6	− 8·2	−4·4	1·5
94	137107	100·0	− 6·5	− 3·3	−3·2	...
95	140027	87·5	+ 3·3	+ 0·8	+2·5	0·7
96	140160	85·2	+ 1·4	+ 1·6	−0·2	0·9 Var.
97	141653	116·6	− 5·6	− 8·5	+2·9	1·6
98	141680	76·6	− 3·5	+ 4·5	−8·0	0·4
99	147835	92·0	− 6·3	− 1·0	−5·3	2·2
100	148112	78·4	− 5·3	+ 3·8	−9·1	0·5 Var.?
101	148783	98·2	+ 3·3	− 2·7	+6·0	0·5
102	152107	98·8	− 1·4	− 2·9	+1·5	0·4
103	152863	82·5	− 0·4	+ 2·5	−2·9	0·8
104	157740	70·8	+10·8	+ 6·2	+4·6	0·7
105	161693	99·8	+ 1·8	− 3·2	+5·0	2·4
106	169981	75·0	+ 8·5	+ 4·9	+3·6	...
107	171978	47·0	+13·3	+13·0	+0·3	1·8
108	178619	59·4	+ 9·8	+ 9·7	+0·1	...
109	180777	116·5	− 3·9	− 8·5	+4·6	0·5
110	183324	43·7	+16·8	+13·7	+3·1	0·9
111	184960	91·3	+ 1·0	− 0·4	+1·4	1·1
112	187340	108·8	0·0	− 6·2	+6·2	0·5
113	187638	78·5	+10·1	+ 3·8	+6·3	0·5
114	193592	94·6	− 2·8	− 1·5	−1·3	0·7
115	194943	21·3	+19·5	+17·8	+1·7	1·1
116	195050	77·6	− 0·2	+ 4·1	−4·3	1·0
117	197461	54·2	+ 9·9	+11·2	−1·3	0·3
118	199951	9·0	+17·6	+18·9	−1·3	0·2
119	203454	80·2	+ 1·2	+ 3·3	−2·1	...
120	204139	21·3	+23·4	+17·9	+5·5	2·5
121	205435	85·8	+ 6·9	+ 1·4	+5·5	0·2
122	205765	41·4	+16·9	+14·3	+2·6	1·7
123	206445	43·4	+ 9·9	+13·9	−4·0	1·7
124	209515	86·2	− 1·2	+ 1·3	−2·5	1·8
125	209625	43·6	+20·4	+13·9	+6·5	...
126	210459	75·7	+ 2·2	+ 4·8	−2·6	1·7
127	211202	19·7	+12·5	+18·0	−5·5	0·7 Var.?
128	213320	38·6	+13·7	+14·9	−1·2	0·6 Var.
129	214994	74·7	+ 6·6	+ 5·0	+1·6	0·5
130	215167	34·6	+21·6	+15·7	+5·9	0·2
131	216228	108·5	−12·4	− 6·1	−6·3	0·2
132	216336	28·6	+16·5	+16·8	−0·3	1·2 Var.?
133	216627	38·7	+18·0	+14·9	+3·1	0·7
134	218700	61·0	+ 8·8	+ 9·3	−0·5	1·6
135	220704	41·2	+15·6	+14·4	+1·2	0·3
136	224427	80·0	− 4·3	+ 3·3	−7·6	0·5

No.	μ (Unit 0″·001)	λ	Parallax (Unit 0″·001)			m	Spectral Type	Absolute Magnitude, M
			Cal.	Trig.	Spectr.			
		°						
35	115	132·3	39	45	...	6·74	Go	+4·70
36	74	91·8	18	15	17	4·51	A2	+0·82
37	26	45·0	9	1	12	4·65	Ko	−0·55
38	27	108·5	7	...	16	5·47	Ao	−0·27
39	55	77·8	14	11	16	5·28	A2	+0·99
40	61	61·1	17	...	13	5·28	Ko	+1·47
41	92	98·2	23	26	26	4·83	A5	+1·65
42	87	114·9	24	47	26	6·03	Fo	+2·91
43	31	98·5	8	...	10*	6·27	Ao	+0·70
44	37	53·5	12	4	13	4·70	K2	0·00
45	60	93·1	15	13	18	5·20	A2	+1·06
46	57	123·4	17	21	14	4·98	A2	+1·13
47	117	78·6	30	24	14	4·64	K2	+2·00
48	71	80·3	18	21	14	4·24	Ko	+0·50
49	27	136·0	10	...	10	5·40	Go	+0·31
50	16	117·3	4	...	20	5·06	A2	−1·68
51	21	116·7	6	...	14*	5·78	Ao	−0·37
52	36	126·2	11	10	16	5·32	A2	+0·55
53	468	106·9	121	...	135*	6·41	G5	+6·83
54	33	148·1	15	3	17	4·64	Ko	+0·59
55	19	149·1	9	...	18	4·92	A2	−0·26
56	204	141·1	81	104	88	4·62	F8	+4·15
57	64	101·3	16	15	22	3·98	G5	+0·03
58	3	158·8	2	...	10	5·28	Ko	−3·11
59	20	161·3	16	...	22	4·80	A2	+0·76
60	17	165·5	17	...	10*	5·75	A3	+1·88
61	61	152·0	32	40	37	3·65	A2	+1·19
62	24	164·4	22	...	10*	6·20	Ao	+2·92
63	13	158·6	9	...	13	6·36	Fo	+1·08
64	88	154·1	50	...	59	5·69	Go	+4·18
65	94	124·9	28	23	20	4·98	Ko	+2·24
66	2	153·5	1	...	20	5·67	A3, G	−4·12
67	86	86·1	21	...	30*	2·01	Ao	−1·33
68	49	108·0	13	...	18	5·23	G5	+0·77
69	51	152·1	27	...	34	4·27	A3	+1·43
70	4	171·0	6	...	15*	5·83	A2	−0·17
71	9	164·0	8	...	11	5·45	Ao	−0·01
72	22	168·8	28	...	12*	5·70	Ao	+2·95
73	29	167·5	33	...	19	4·62	G5	+2·23
74	14	160·0	10	18	19	4·54	A2	−0·42
75	35	123·0	10	18	15	4·29	Ko	−0·63
76	53	161·0	40	...	27	4·47	A5	+2·50
77	57	146·3	26	...	26	6·41	F5	+3·44
78	23	153·0	13	10	32	3·65	Fo	−0·85
79	7	141·1	3	...	11*	5·87	Ao	−1·89
80	85	86·7	21	...	33	2·84	G5	−0·54
81	40	126·2	12	28	6	4·97	Ma	+0·42
82	25	126·5	8	32	11	5·18	Ko	−0·39
83	51	107·2	13	25	14	4·90	G5	+0·50
84	13	138·8	5	36	12	4·97	Ko	−1·58
85	126	67·6	34	32	24	4·68	Ko	+2·33

No.	μ (Unit 0″·001)	λ	Parallax (Unit 0″·001)			m	Spectral Type	Absolute Magnitude, M
			Cal.	Trig.	Spectr.			
		°						
86	18	136·0	6	...	18*	5·83	A5	−0·14
87	45	119·0	13	...	10*	5·64	Ao	+1·18
88	20	99·2	5	22	9	5·26	Ko	−1·24
89	11	131·8	4	...	8	6·32	G5	−0·84
90	35	118·5	10	...	10*	6·57	A2	+1·55
91	64	122·5	19	10	24	4·60	A5	+0·97
92	110	100·8	28	...	31	5·31	Fo	+2·52
93	29	115·5	8	...	10*	5·98	A2	+0·50
94	236	100·0	60	68	57	5·05	Go	+3·92
95	34	87·5	8	...	8	5·97	G5	+0·59
96	43	85·2	11	...	17	5·26	A*op*	+0·41
97	71	116·6	20	13	20	5·13	A2	+1·60
98	62	76·6	16	31	14	5·33	Ko	+1·32
99	20	92·0	5	...	8*	6·20	A2	−0·30
100	77	78·4	20	33	22	4·53	A*op*	+0·99
101	26	98·2	6	...	6	5·02	M*b*	−0·92
102	66	98·8	17	4	21	4·86	A2*p*	+0·96
103	28	82·5	7	...	7	6·33	Ko	+0·59
104	33	70·8	9	...	14*	5·69	A2	+0·39
105	28	99·8	7	...	10*	5·70	Ao	−0·04
106	28	75·0	7	...	13	5·71	A2	0·00
107	25	47·0	8	...	10*	5·80	Ao	+0·45
108	104	59·4	30	41	...	6·46	F5	+3·85
109	130	116·5	36	46	31	5·06	Fo	+2·84
110	35	43·7	13	...	10*	5·77	Ao	+1·27
111	194	91·3	48	35	38	5·65	F5	+4·06
112	26	108·8	7	...	11	5·90	Ao	+0·06
113	12	78·5	3	...	7	6·21	G5	−1·40
114	27	94·6	7	0	15	5·71	Ao	−0·16
115	28	21·3	19	46	25	4·96	Fo	+1·38
116	76	77·6	19	19	...	5·45	Ao	+1·89
117	54	54·2	17	8	29	4·53	A5	+0·63
118	9	9·0	14	29	10	4·71	G5	+0·47
119	208	80·2	52	...	41	6·46	F8	+5·06
120	40	21·3	27	...	8	6·03	Ko	+3·23
121	94	85·8	23	4	27	4·22	Ko	+1·07
122	29	41·4	11	...	10	6·27	A2	+1·46
123	6	43·4	2	...	5	5·80	K5	−2·49
124	38	86·2	9	...	12*	5·52	Ao	+0·42
125	52	43·6	19	10	19	5·23	A3	+1·60
126	27	75·7	7	3	21	4·38	F5	−1·43
127	16	19·7	12	6	10	5·19	G5	+0·55
128	28	38·6	11	17	18	4·89	Ao	+0·12
129	27	74·7	7	...	17	4·85	Ao	−0·89
130	39	34·6	17	10	9	4·88	K5	+1·04
131	139	108·5	36	38	28	3·68	Ko	+1·49
132	42	28·6	22	40	17	4·52	Ao	+1·22
133	47	38·7	19	42	40	3·51	A2	−0·13
134	20	61·0	6	...	9	5·34	B8	−0·88
135	78	41·2	29	3	15	4·52	K5	+1·85
136	49	80·0	12	...	11	4·75	M*a*	+0·20

trigonometric parallaxes ; it is found that the probable error of the difference "calculated *minus* trigonometric" is just ± 0″·010, which is rather larger than the value (0″·008) obtained similarly from 18 stars in Paper A. In the same way, the 19 stars with spectroscopic parallaxes give the small probable error of ± 0″·004 for the difference "calculated *minus* spectroscopic."

6. The last three columns of Table IV give the apparent magnitudes, spectral types and the absolute magnitudes derived * from the calculated parallaxes. The absolute magnitudes obtained in this way provide a further criterion not, however, of a generally trustworthy nature owing to uncertainty as to what constitutes a reliable estimate of the spread of absolute magnitudes for any given spectral type (main series or giant branch).

Table V gives a summary of the relation between absolute magnitude and spectral type for all the stars assigned to the cluster in Paper A and

TABLE V

Absolute Magnitude and Spectral Type

	A0*p*	A0	A2*p*	A2	A3	A5
No. of Stars	2	9	2	7	2	2
Average *M*	−0·57	+0·81	+0·47	+1·51	+2·24	+2·69
Average Residual	0·26	0·41	0·05	0·42	0·17	0·71

	F0	F5	F8	G0	G5 (Giant)	G5 (Dwarf)	K0 (Giant)
No. of Stars	4	3	3	1	3	1	3
Average *M*	+3·27	+3·76	+4·48	4·70	+0·43	+6·83	+1·43
Average Residual	0·40	0·21	0·39	...	0·27	...	0·62

in the present investigation. Where the spectral types apply, these results are very similar to those given in Table VII of Paper A. The new stars include three G5 giants and one G5 dwarf. There are also three K0 stars with an average absolute magnitude of 1·43 (with, however, a considerable spread) as compared with the average absolute magnitude of 1·12 (with negligible spread) found for the four stars of this spectral class in the Taurus Cluster.†

There appears to be little doubt as to the co-existence of giants and dwarfs in the moving clusters. This point is further illustrated for the Ursa Major Cluster by the Hertzsprung-Russell diagram, in which all the cluster stars of Paper A and the present investigation are represented by dots and the doubtful stars of both papers by crosses.

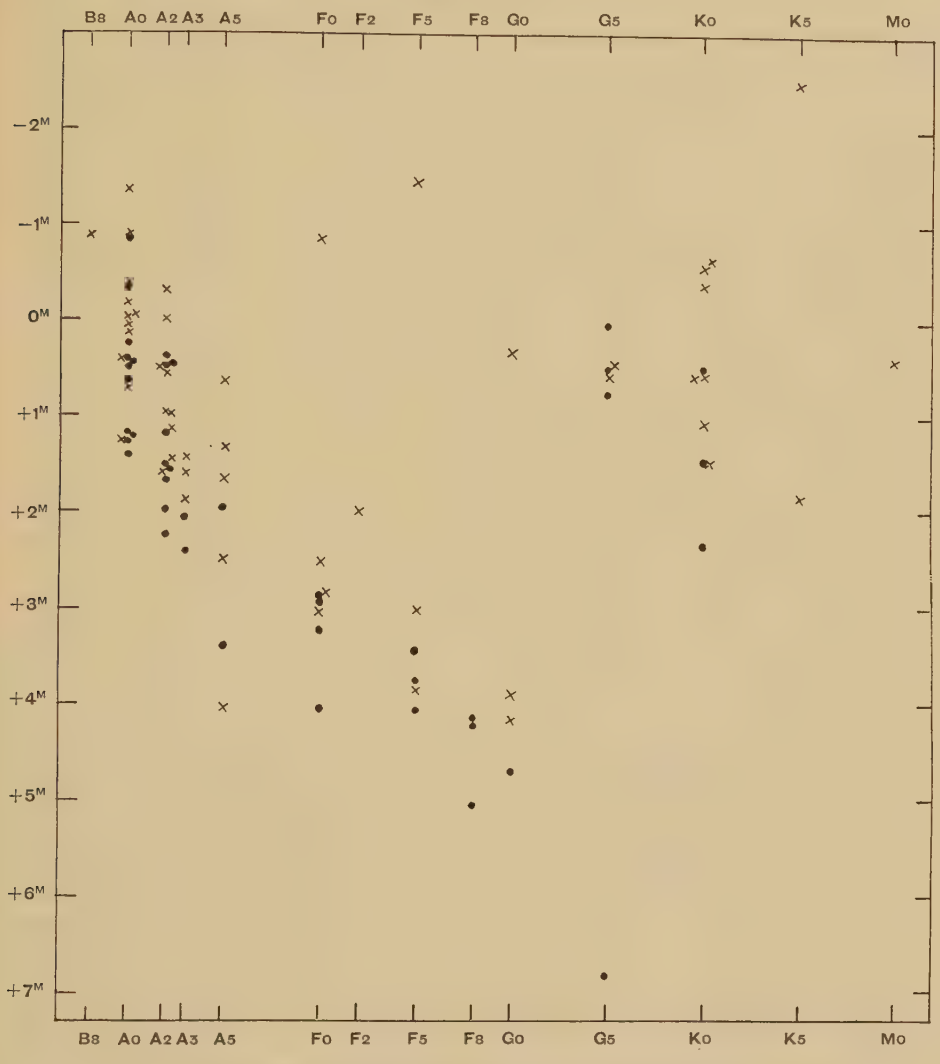
7. We consider now the spatial co-ordinates of the cluster stars of Table I.

Table VI gives, in parsecs, the heliocentric galactic co-ordinates (x, y, z) of each star, derived from the calculated parallax. In Paper A it was found

* For this purpose a fourth decimal place was retained in the values of the calculated parallaxes.

† *M.N.*, **99**, 168, 1939 (Table VI).

that 10 out of the 23 cluster stars form a compact core, the centre of which was taken to be the centre of the cluster. It is noteworthy that of the cluster stars considered in the present paper only one (No. 35)—and that



Hertzsprung-Russell Diagram for the Ursa Major Cluster.

Cluster Stars : dots.
Doubtful Stars : crosses.

not a star from the list of Paper B—is to be added to this central concentration. It was tentatively suggested in Paper A that the cluster stars were roughly distributed along a certain axis; the co-ordinates (X, Y, Z) of the stars referred to the centre of the cluster as origin and to axes based on this particular direction are given also in Table VI. With one or two exceptions the new material supports the suggestion just noted. It would also appear from the range in the Z co-ordinates that the diameter of the cluster in this

direction is about 150 parsecs, the new material making no substantial extension of the cluster, as may be inferred from the Z co-ordinates in Table VIII of Paper A.

TABLE VI

No.	x	y	z	X	Y	Z
35	+ 1·8	+12·6	+22·2	+ 2·0	+ 0·7	+ 2·2
40	− 12·3	− 5·7	−57·2	+ 29·4	−17·6	−73·6
42	− 10·6	+39·4	− 8·9	+ 6·8	+27·5	−30·9
48	− 32·4	−14·7	−42·7	+ 4·8	−26·6	−71·1
53	− 7·4	− 1·9	− 3·2	+ 6·7	−13·8	−24·4
56	− 11·2	+ 5·0	− 0·2	+ 2·0	− 6·9	−23·7
57	− 52·1	−27·8	−20·4	− 23·5	−39·7	−61·7
61	− 29·6	+ 6·0	+ 8·0	− 18·1	− 5·9	−25·8
68	− 55·4	−52·4	+10·5	− 41·7	−64·3	−36·6
77	− 23·2	− 5·5	+30·2	− 23·7	−17·4	− 3·4
83	− 18·8	−53·9	+51·4	− 30·4	−65·8	+17·2
85	0·0	−29·4	+ 0·8	+ 11·0	−41·3	−17·3
87	+ 1·3	−17·6	+74·8	− 24·8	−29·5	+47·5
90	+ 23·3	+14·1	+96·2	− 16·4	+ 2·2	+77·0
96	+ 61·8	−11·7	+65·6	+ 32·2	−23·6	+69·8
107	+125·0	− 4·1	+ 3·0	+118·2	−16·0	+47·2
111	+ 12·8	+15·7	+ 5·0	+ 20·1	+ 3·8	− 7·2
119	+ 11·4	+15·3	− 2·4	+ 22·5	+ 3·4	−14·3
132	+ 18·1	− 6·5	−41·2	+ 47·7	−18·4	−44·6

8. *Summary.*—A list of 101 stars regarded as members of the Ursa Major Cluster by Nassau and Henyey is further investigated according to criteria depending on position angle of proper motion, radial velocity, parallax and absolute magnitude. Including Gr. 1970 (additional to the list referred to), 19 stars are believed to belong to the cluster, while 47 are possible members. The remaining stars (36 in number), it is concluded, are not cluster stars.

The total membership of the cluster is 42 (of these, 23 are dealt with in a previous paper). Ten stars are within five parsecs of the centre of the cluster. The greatest diameter of the cluster is found to be about 150 parsecs.

Of the cluster stars 36 belong to the main series in the Hertzsprung-Russell diagram, while 3 are G5 giants and 3 are Ko giants.

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THE INFLUENCE OF THE VARIABILITY OF THE MEAN LATITUDE OF SUNSPOTS ON THE RECURRENCE TENDENCY OF MAGNETIC DISTURBANCES

G. H. Archenhold, Ph.D.

(Communicated by the Astronomer Royal)

1. Some terrestrial phenomena which are dependent on the Sun's activity show a recurrence interval of approximately the same length as the rotation period of the Sun. For example, C. Chree and J. M. Stagg * demonstrated a recurrence interval of 27·0 days in terrestrial magnetism, and the present author † found a periodicity of 27 to 28 days in the frequency of haloes around the Sun, which have their origin in high terrestrial clouds. As is well known, the rotation of the Sun is not constant, but varies as a function of latitude. Also, the mean latitude of sunspots changes systematically during a sunspot cycle. In the first years of a sunspot cycle—that is, after a sunspot minimum—the mean equator distance of the spots is about 20° ; at the end only a little more than 5°. The synodic rotation period of the Sun corresponding to these latitudes is 27·5 days and 26·9 days respectively. If, then, the source of the radiation which influences the terrestrial phenomena is connected with the areas of sunspots, a sensible difference between the recurrence intervals in years of low and of high sunspot latitude would be expected. Using the magnetic character figures of the years 1906 to 1925, Chree and Stagg came to the conclusion that the suggested effect could not be revealed in the case of terrestrial magnetism. Since there are now more data available, both of years following and preceding the period mentioned, the question of the variability of the recurrence interval in terrestrial magnetism will be resumed in the present paper. The data, which go back to the year 1847, are not uniform, and different methods of analysis have been used for different periods. These are given in paragraphs 2, 3, 5 and 6. In paragraph 4 a new view-point is introduced regarding the grouping of the years for which the greatest difference of the recurrence interval may be expected.

2. The method adopted for calculating the recurrence interval of magnetic disturbances was as follows. In the list of international character figures, published by the Royal Meteorological Institute, De Bilt, Netherlands, all days having a character figure equal to or higher than 1·1 were picked out year by year. The days following a selected calendar day were numbered 1, 2 and so on ; the days preceding were numbered -1, -2 and so on. The average of the character figures belonging to a day n was then tabulated in the interval for n -31 to -24 and $+24$ to $+31$. The highest figure

* *Phil. Trans. Roy. Soc.*, A, **227**, 21, 1927.

† *Gerlands Beiträge zur Geophysik*, **53**, 395, 1938.

usually belongs to the days ± 27 or ± 28, indicating the recurrence interval. Owing to the fact, pointed out by Chree and Stagg, that a magnetic disturbance, lasting several days, rises more rapidly than it declines, the figures following or preceding the biggest value are not symmetrical about the maximum. This skewness of the curves is eliminated by combining the values of the days $-n$ and $+n$, a method due to Chree and Stagg.

The result obtained for the two groups of years 1930–1933 and 1934–1937 is given in fig. 1. Since character figures for January 1938 were not at hand, disturbed days in December 1937 could not be used as selected

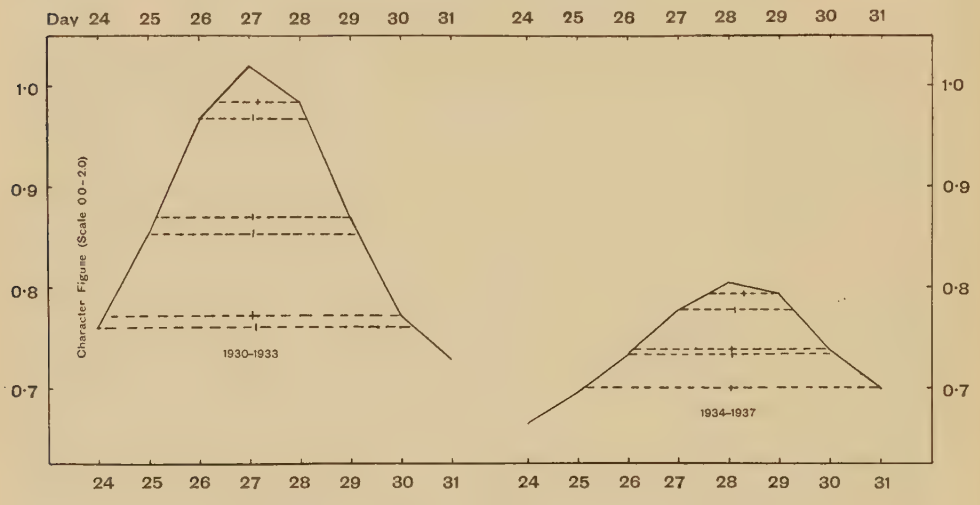

FIG. 1.—*Mean magnetic character in the interval* 24 *to* 31 *days counted from the disturbed days in the years* 1930–1933 *and* 1934–1937.

days. The year of the least solar activity was 1933. The mean latitude of sunspots was low from 1930 to 1933, and high from 1934 to 1937.

In order to trace the recurrence interval with more accuracy, horizontal lines were drawn through each point given by a calculated value, and the mid-points of the resulting chords were taken. If there were no accidental deviations these points would lie on a vertical line, since any skewness has been eliminated as explained above. This is nearly the case, the total scatter of the points being only a few tenths of a day.

From the figure it will be seen that the mean recurrence interval is about 27 days for the four years preceding the minimum year and about 28 days for the four years following. As can be seen from curves for the individual years, not reproduced here, the jump in the length of the interval takes place at the time when the last sunspots of the cycle, which have a low latitude, disappear and the sunspots of the new cycle having a high latitude begin to prevail.

3. A similar analysis may be made for the years around the sunspot minima of 1913 and 1923, using the data and method of Chree and Stagg (*loc. cit.*) in which the five most disturbed days of the month and the five quietest are chosen as days $n = 0$. Data for the years 1907–1924 have been

given by these authors and is supplemented by the Table below, which contains data for the two years 1925 and 1926. In addition to the values for the days 25 to 29, Chree and Stagg have published figures for the days 52 to 56 of which we make use to determine also the double length of the recurrence interval.

Data for the Years 1925 *and* 1926, *supplementing Table* 17 *given by Chree and Stagg* (loc. cit.)

Year	Day 25	26	27	28	29
1925	198	350	417	412	238
1926	92	275	613	495	248

In fig. 2 (*a*) the curves of recurrence are given for four groups of years. The two groups 1910–1912 and 1920–1922, both representing years preceding

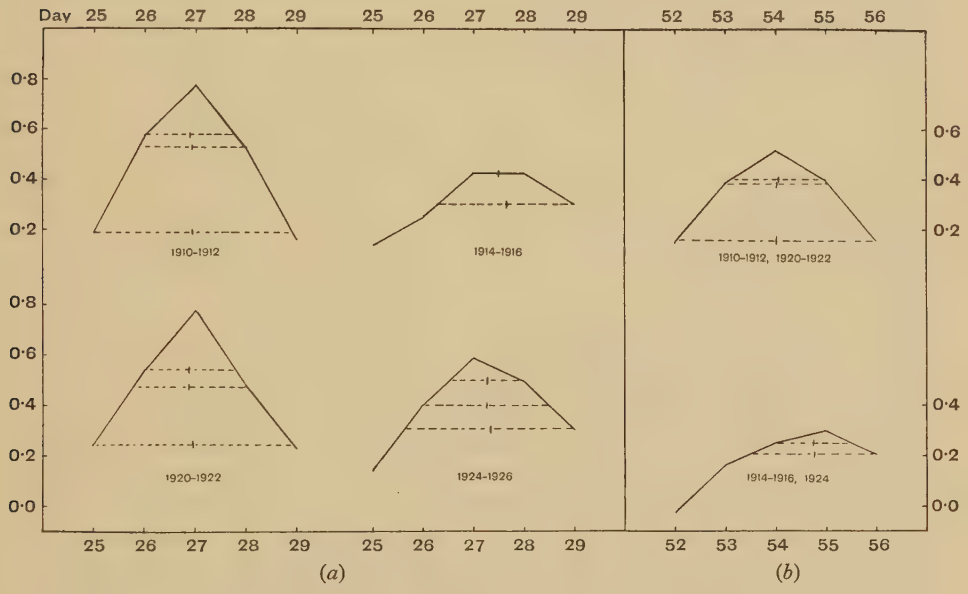

FIG. 2.—*Curves showing the recurrence tendency of magnetic activity before and after the sunspot minima of* 1913 *and* 1923.

a sunspot minimum, have a recurrence interval of 26·9 days. The two other groups of years following a sunspot minimum, 1914–1916 and 1924–1926, give a larger recurrence interval of about 27·4 days. The double length of the recurrence intervals deduced from the values for the days 52 to 56 (fig. 2 (*b*)) is 54·0 days and 54·7 days respectively. These results confirm that there is a jump in the length of the recurrence interval at the time of a sunspot minimum. The mean latitude of sunspots was 19° in the years 1914–1916 and 20° in the years 1924–1926. The corresponding synodic rotation period of the Sun's photosphere is 27·5 days—that is, only a small fraction greater than the observed recurrence interval of the Earth's magnetic disturbances.

4. Before communicating further material, we will draw attention to

another property of the curves in figs. 1 and 2. In addition to the difference of the length of the recurrence interval in years before and after a sunspot minimum, there is a remarkable difference in the amplitude of the curves. The amplitude is much greater in years before than in years after a minimum. This may be explained by the fact that a sunspot crossing the Sun's disk in a low latitude comes nearer to the centre of the disk than a sunspot in a high latitude, and has a correspondingly greater effect on terrestrial magnetic phenomena.

This difference of amplitude becomes important when the average is taken of curves for several years. Owing to their greater amplitude the curves for years of low sunspot latitude will have more weight than those for years of high sunspot latitude. The average recurrence interval of magnetic disturbances will therefore be smaller than expected from the rotation period of the Sun in the mean latitude of the spots. This seems to be the reason for the relatively low value of 27·0 days found by Chree and Stagg for the recurrence interval of terrestrial magnetic phenomena as compared with the average rotation period of sunspots which is about $27\frac{1}{4}$ days.

Another consequence of the fact that sunspots in low latitudes have a greater influence on the Earth's magnetism than those in high latitudes can be found in the case of the minimum years of the Sun's activity. In these years there exist on each hemisphere of the Sun two different zones of sunspot activity, one near the equator and a second in a latitude of about 20–30°. Although the mean equator distance of the sunspots may be very high, the recurrence interval of magnetic disturbances will be found to be very short, as the shorter rotation period of the low latitude sunspots will dominate. Examples for this are the minimum years 1913 and 1923 with a mean sunspot latitude of 23° and 15° respectively, but a recurrence interval smaller than 27·0 days. When grouping the years of high sunspot latitude, the years of sunspot minima with their short recurrence interval and their great weight will compensate for the longer interval of the other years. It seems therefore justified to exclude the minimum years from the group of high latitude years, because their mean sunspot latitude does not represent the latitude of the most effective spots, which are situated near the Sun's equator. Moreover, it seems reasonable that a strong correlation cannot be found between the length of the recurrence interval and the mean sunspot latitude. The introduction of an "effective" latitude, which may be defined as the mean of sunspot latitudes weighted according to the influence of the spots on the Earth's magnetism, should improve the correlation.

5. Fig. 3 gives the results as regards the recurrence tendency in terrestrial magnetism for the years preceding and following the sunspot minima of 1889 and 1901. For these years lists have recently been published by the Meteorological Institute, De Bilt, containing the dates of the five most disturbed days of each month and of the five days with the quietest magnetic conditions. The figure shows diagrammatically how often a disturbed or quiet day follows a day of the same kind after an interval of 24 to 31 days.

The crest of the curves was determined in the same manner as described in paragraph 2. For the two groups of years before the sunspot minima

the length of the recurrence interval is found to be 27·1 and 27·2 days. For the years of high sunspot latitude after the minima the interval is 27·6 and 27·3 days. Again the amplitude of the curves is greater for the years of low latitude than of high latitude, and the recurrence interval shows the same characteristics.

6. The examination of the length of the recurrence interval for still earlier years is based on estimations of the daily magnetic character number from magnetic traces obtained at the Royal Observatory, Greenwich. The

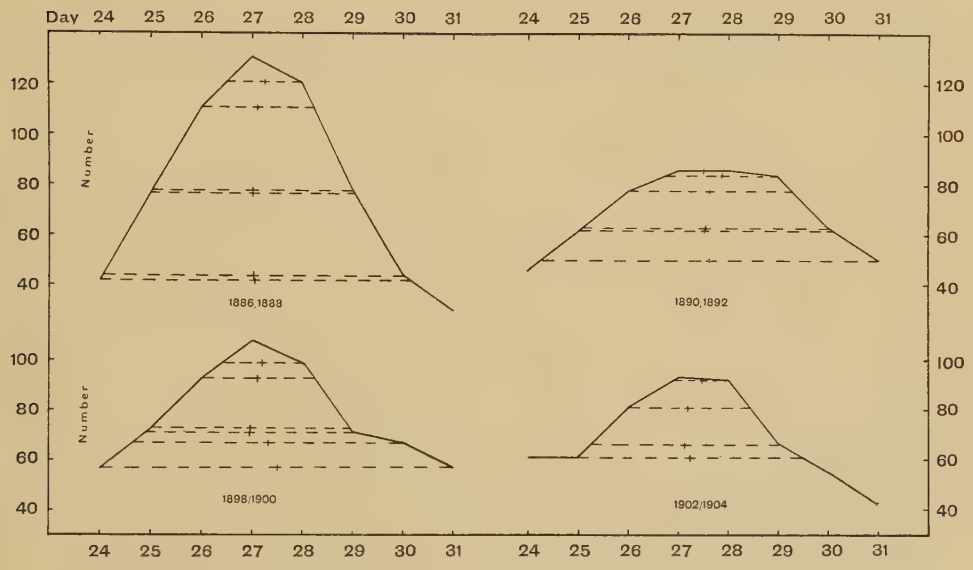

FIG. 3.—*The recurrence interval about the sunspot minima of* 1889 *and* 1901.

estimations were made by W. M. Witchell, Superintendent of the Magnetic Department of the Observatory, on a scale 0–7 from 1847 September 27 to 1889 December 31. The author is much indebted for the permission to use the unpublished data for the present investigation.

The method adopted was the same as that described in paragraph 2, with the one difference that in consequence of the altered scale the selected days were those with character numbers equal to or higher than 4. Since the resulting curves for the groups of every three years before and after the sunspot minima of 1856, 1867 and 1878 are not sufficiently free from accidental deviations, the results for the years preceding a minimum and for those following have been combined and are given in fig. 4. From the left-hand curve in fig. 4 a recurrence interval of 26·9 days is derived for the pre-minimum years. In the case of the post-minimum years even the sum of all nine years does not give good symmetry as may be seen from the upper right-hand curve. The lower right-hand curve in fig. 4 is smoothed by taking the mean of every three consecutive values. The latter curve gives a recurrence interval of 27·3 days.

7. Summarizing the results obtained for all groups mentioned above, we

find a mean recurrence interval of 27·02 days for the years before sunspot minima and of 27·52 days after the minima. The mean error of the first value is ± 0·13 day and that of the second ± 0·05 day. The difference of 0·5 day between the recurrence intervals in years before and after the sunspot minima is thus 3·6 times the mean error, which is ± 0·14 day.

8. In this paragraph the variation of the recurrence interval of magnetic disturbances is studied as a function of the phase in the sunspot cycle. Since the jump of the recurrence interval takes place during the minimum years

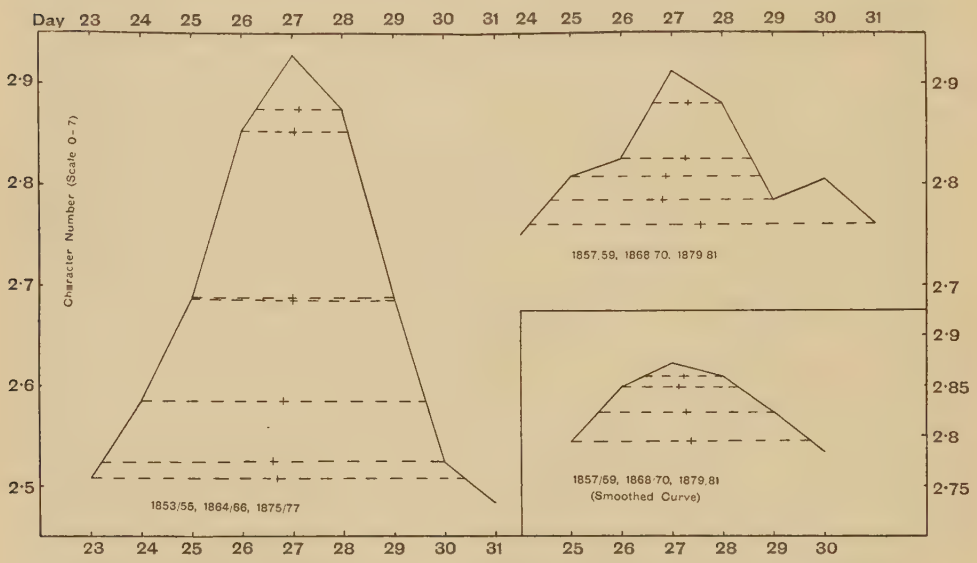

FIG. 4.—*The recurrence interval before and after the sunspot minima of* 1856, 1867 *and* 1878.

of sunspot activity, the phase is counted forward and backward from the minimum years.

For all years between 1884 and 1937 the recurrence interval was determined. Only the years 1914 and 1937 did not give a reliable result since the amplitudes of the curves were too small. Each open circle in fig. 5, which shows the variability of the recurrence interval as a function of the phase of the cycle, is the mean of four or five individual values. The recurrence interval to be expected from the synodic rotation period of the Sun calculated for the mean latitudes of the spots is indicated by crosses. The values of the mean daily rotation angle used for this compilation were taken from the table given by Abetti.* The values of the mean equator distance of the spots were taken from the Greenwich publications. The agreement between the observed and the calculated values is fairly good. Apart from accidental deviations, the recurrence interval shortens continually from the year after the sunspot minimum to the year before the minimum. The minimum years themselves give an intermediate value. The variation of the recurrence

* *Handbuch der Astrophysik*, **4**, 101, 1929.

interval during a sunspot cycle can be fairly well represented by the two straight lines drawn in fig. 5.

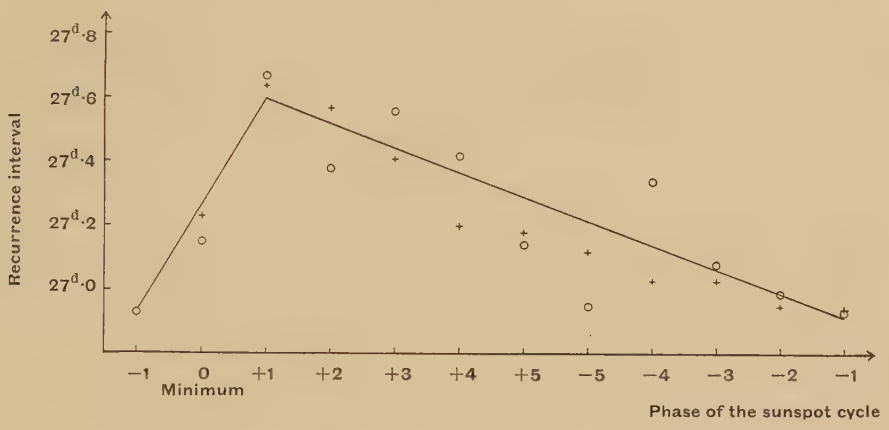

FIG. 5.—*The variation of the recurrence interval during the sunspot cycle.*
o *Observed interval in terrestrial magnetism.*
\+ *Calculated rotation period of the Sun in the mean latitude of the sunspots.*

9. *Summary.*—It is pointed out that the recurrence interval of terrestrial magnetic disturbances is definitely smaller in years preceding a sunspot minimum than in years following a minimum. The difference between each three years before and after a minimum is found to be 0·5 day with a mean error of ± 0·14 day. The recurrence interval shortens continually from the beginning of the cycle to the end as is to be expected from the decline of the mean equator distance of the sunspots. In years with sunspot zones, both near the equator and in higher latitudes, the shorter recurrence interval of the equator belt prevails, because disturbed areas of the Sun's surface are the more effective on the Earth's magnetism the smaller their mean distance from the equator.

In conclusion the writer wishes to thank Professor S. Chapman, Dr. J. M. Stagg, Mr. H. W. Newton and Dr. H. R. Hulme for their help in preparing this paper.

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NOTE ON THE INTEGRATION OF THE EQUATION OF THE FORMATION OF ABSORPTION LINES

H. R. Hulme

1. In the analysis of line intensities it is important to consider the variation with optical depth (τ) of the quantity $\eta = l/k$, which is the ratio of the line absorption or scattering to the continuous absorption. We have adopted the notation of Eddington's classical paper *, and further explicit definitions will not be given here. Special cases have been considered by Eddington (*loc. cit.*) and others, and the general case has been solved approximately by B. Strömgren †, using a perturbation method, and by Pannekoek ‡ with numerical methods. A brief account of another special case is perhaps not without interest and is given in section 2. In section 3 a procedure for solving the general case is indicated.

2. The case considered is that where

$$\frac{1}{1+\eta} = \alpha + \beta\tau + \gamma\tau^2, \tag{1}$$

which is more general than Eddington's case by virtue of the τ^2 term. We shall assume that ϵ, the collision term, is zero, and that $\mathcal{J} = \mathcal{J}_T = H(2+3\tau)$. We then have for $\mathcal{J}_\nu'$, the intensity within the line,

$$(\alpha+\beta\tau+\gamma\tau^2)\frac{d^2\mathcal{J}_\nu'}{d\tau^2} + (\beta+2\gamma\tau)\frac{d\mathcal{J}_\nu'}{d\tau} - 3\mathcal{J}_\nu' = -3H(2+3\tau). \tag{2}$$

The particular integral is given by

$$\begin{aligned} \mathcal{J}_\nu'/H &= 2 + 3\beta/(3-2\gamma) + 9\tau/(3-2\gamma) \\ &= a + b\tau, \quad \text{say.} \end{aligned} \tag{3}$$

To obtain the general solution we put

$$\left.\begin{aligned} z &= \frac{\tau}{c} + \frac{\beta}{2\gamma c}, \\ c^2 &= (\beta^2 - 4\alpha\gamma)/4\gamma^2, \\ n(n+1) &= 3/\gamma, \end{aligned}\right\} \tag{4}$$

and on equating the left-hand side of (2) to zero we get

$$(1-z^2)\frac{d^2\mathcal{J}_\nu'}{dz^2} - 2z\frac{d\mathcal{J}_\nu'}{dz} + n(n+1)\mathcal{J}_\nu' = 0,$$

which is Legendre's equation of order n.

Two suitable fundamental solutions are given by §

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* *M.N.*, **89**, 623, 1929. † *Ap. J.*, **86**, 1, 1937.

‡ *Publ. Astr. Inst. Univ. Amsterd.*, No. 4, 1935.

§ Hobson, *Spherical and Ellipsoidal Harmonics*, chap. v.

$$F_1(z) = F(-n, n+1 ; 1 ; (1+z)/2)$$

and

$$F_2(z) = F(-n, n+1 ; 1 ; (1-z)/2),$$

where F is the hypergeometric function. $F_1(z)$ has a singularity on the real axis at $z=1$, where it becomes logarithmically infinite, and $F_2(z)$ has a similar singularity at $z=-1$. The two solutions are, in fact, reflections of each other in the origin, so that the sign of c is immaterial. The solution of equation (2) may therefore be written

$$\mathcal{J}_\nu'/H = a + b\tau + AF_1(z) + BF_2(z). \tag{5}$$

It appears that β is positive and γ is negative in practice, so that a minimum value of η occurs when $\tau = -\beta/2\gamma$. If k increases with optical depth faster than l_ν, η will decrease with increasing τ, and equation (1) will only be valid as far as $\tau = \tau_1 \leqslant -\beta/2\gamma$. This is so in the example quoted at the end of the paragraph, in which $k \sim$ (electron pressure)$/T^{9/2}$. From τ_1 we may join on a solution of the form $1/(1+\eta) = \lambda + \mu\tau$, adjusting the constants so that the values of η and $\dfrac{d\eta}{d\tau}$ are continuous. As the region $\tau \leqslant -\beta/2\gamma$ is strictly within the region $z=-1$ to $z=+1$, it is essential to use both F_1 and F_2. The solutions are therefore given by (5), from τ to τ_1, and by

$$\mathcal{J}_\nu'/H = 2 + \mu + 3\tau + DK_0(x) \ *$$

from $\tau = \tau_1$ to $\tau = \infty$, where

$$x = \left\{\frac{12(\lambda+\mu\tau)}{\mu^2}\right\}^{\frac{1}{2}},$$

D is a constant and K_0 the Bessel function. The constants A, B and D are determined from the conditions that $\mathcal{J}_\nu'$ and H_ν' are continuous at τ_1, and $\mathcal{J}_\nu' = 2H_\nu'$ at $\tau = 0$.

We then have

$$H_\nu'/H = \mathcal{J}_\nu'/2H = \tfrac{1}{2}\{a + AF_1(z_0) + BF_2(z_0)\},$$

which gives the required darkening. The actual formulæ are complicated, and it is better to substitute the numerical values before eliminating. The values of the hypergeometric functions are calculated quite simply from the series formula.

We have examined the case of ionised calcium in the Sun, using the values of η given by Woolley.† A good fit may be obtained by taking

$$\frac{1}{1+\eta} = 0{\cdot}13 + 5{\cdot}0\tau - 20{\cdot}0\tau^2$$

from $\tau = 0$ to $\tau = 0{\cdot}118$, and

$$\frac{1}{1+\eta} = 0{\cdot}41 + 0{\cdot}275\tau$$

from $\tau = 0{\cdot}118$ to $\tau = \infty$. We obtain the result, for Ca^+ in the Sun,

$$r_\nu = H_\nu'/H = 0{\cdot}63.$$

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* Eddington, *loc. cit.*, equation (38*c*).

† *M.N.*, **92**, 495, 1932.

Woolley gives 0·65 by an approximation using two straight lines, so that the agreement is very close.

3. In the most general case, when η, ϵ and $\mathcal{J}_T$ are arbitrary functions of τ, the equations of transference can be solved on the differential analyser.* The equations are (Eddington, *loc. cit.*)

$$\frac{dH_\nu'}{d\tau} = (1+\epsilon\eta)(\mathcal{J}_\nu' - \mathcal{J}_T),$$

$$\frac{d\mathcal{J}_\nu'}{d\tau} = 3(1+\eta)H_\nu'.$$

Putting

$$dt = (1+\eta)d\tau, \tag{6}$$

whence t is the optical depth in frequency ν, we have

$$\frac{d^2\mathcal{J}_\nu'}{dt^2} = \frac{3(1+\epsilon\eta)}{(1+\eta)}(\mathcal{J}_\nu' - \mathcal{J}_T). \tag{7}$$

We shall assume that ϵ, η and $\mathcal{J}_T$ are given graphically as functions of τ. A simple graphical integration of (6) gives the relation between τ and t, so that ϵ, η and $\mathcal{J}_T$ may be found as (graphical) functions of t. The equation (7) then takes the form

$$\frac{d^2\mathcal{J}_\nu'}{dt^2} + \phi(t)\mathcal{J}_\nu' + \lambda(t) = 0,$$

where $\phi(t)$ and $\lambda(t)$ are known functions which may be graphed against t. This equation is easily solved on any differential analyser which has two input tables, for $\phi(t)$ and $\lambda(t)$, and three integrator units. The solution is determined by the boundary conditions $\mathcal{J}_\nu' = 2H_\nu'$ at $\tau = 0$, together with the condition that $\mathcal{J}_\nu' \to \mathcal{J}_T$ for large τ, which latter condition may be written $\frac{dH_\nu}{d\tau} \to 0$ as $\tau \to \infty$. Let us consider, for example, the case where $\mathcal{J}_T = H(2+3\tau)$, where H is a constant representing the total flux just outside the line. The method would be to try solutions with initial conditions $\mathcal{J}_\nu' = 2H_\nu'$ and $H_\nu' = rH$, when $\tau = 0$, a number of values of r being considered. That solution, usually found by interpolation, which gives $\frac{dH_\nu}{d\tau} \to 0$ as τ becomes great is the correct one, and the corresponding value of r gives the required intensity, namely H_ν'/H.

The author's thanks are due to Dr. R. v. d. R. Woolley and Professor H. S. W. Massey for suggestions and advice.

Summary

In the integration of the equation of the formation of absorption lines, the special case in which $1/(1+\eta) = \alpha + \beta\tau + \gamma\tau^2$ is discussed. A brief account is also given of the possibility of using the differential analyser to solve the most general case.

* See, for example, Hartree, *Mathematical Gazette*, **22**, No. 251, 342, 1938.

A MODIFICATION OF THE MICHELSON INTERFEROMETER METHOD FOR THE DETERMINATION OF STELLAR DIAMETERS

P. Lacroute

In a paper published in the *Monthly Notices* (**99**, 141, 1939) Fürth, Sitte and Appel propose an experimental arrangement which may be used for the measurement of stellar diameters by the Michelson method, even if there is strong air perturbation. The arrangement consists in the observation of secondary fringes (fringes S) located somewhat behind the focus of the objective, instead of observation of Michelson fringes (fringes M) located in the focus.

As the disappearance of fringes M involves the disappearance of fringes S, stellar diameters can be derived from the visibility of fringes S.

We do not agree with the authors.

1. If in the modified experimental arrangement of Michelson fixed fringes F are found somewhere, *i.e.* fringes insensible to movement of the Michelson fringes, they would be useless.

When Michelson fringes are indistinct for certain values of stellar diameters, it means that there are several systems of Michelson fringes, laterally displaced in their own plane from one another and formed by light issuing from different regions of the disc of the star. Passing from one system to another, the light is not coherent. In a plane of hypothetically stable fringes F, each of these systems M will give independently a system of fringes F, and all these systems of fringes F will be superposed.

Thus every element of the star gives rise to an exactly similar and superposed set of fringes F, and the observation of fringes F will give no indication of the stellar diameter.

2. If the case of fringes S is directly examined, it can easily be seen that by a simple application of the theory of diffraction for a plane behind the focal plane, as it is applied for the focal plane to explain fringes M, fringes are also obtained (fringes S) and their distance is always near that of fringes M —somewhat larger. They disappear together with fringes M. They can only be observed in the zone where the beams of light issuing from the two slits cover each other, that is to say, near the focus, and all the nearer as the angle of the two beams is larger, which means that the slits are more distant. These fringes S are somewhat less distinct than fringes M because beyond the focal plane the distribution of the intensity in the beams issuing from the two slits is not the same in every point. All the features of the fringes mentioned by the authors are thus explained, except the stability. It is indeed observed that on this point nothing distinguishes fringes S from fringes M. If we introduce for one beam of light a path difference, the systems of fringes M and fringes S are both deviated by the same number of fringes.

3. Now it remains only to explain how the stability of fringes S could have been thought to have been observed. The following explanations are only conjectures, for the reader could miss certain experimental details. The path differences introduced between the two beams of light seem to be probably too small. Indeed, as the fringes were observed in monochromatic light any permanent deviation of the fringes, *i.e.* every permanent path difference introduced between the beams, could not be detected. We must only consider fluctuating path difference, only made evident by photographs. If we act on beams of light traversing an air path of 25 cm., a difference of temperature of 1° C. causes a deviation of 1/2 fringe. But, for example, in the case of the plates 7, 8 and 9 the slits are rather near, being only 18 mm. apart and 5 mm. wide, and as we need only take into account the mean differences of temperature produced on the 25 cm. of perturbed course we see that we can accept differences of temperature of about 4° between two consecutive regions of air of a diameter of 20 mm. It is very possible that the perturbation of the temperature is less than this, for the gas stove is rather far from the lens, *i.e.* from the beams. The plates 9 and 12, and chiefly 12, show, however, that fringes S are still somewhat sensitive to the created perturbations.

We have now to explain how the complete confusion of fringes M has been obtained under apparently the same conditions. Plate 6, which demonstrates it (even if it has been obtained in the same conditions as the plates 9, 12, 15 and 17), is not convincing. Indeed, this plate is considerably over-exposed in its central zone, and if there are fringes there we cannot see them; only the lateral zones could be of any use. But we see that unperturbed fringes S are also less distinct on the border of the systems of fringes. The reason is probably that in the centre of the fringes the two interfering beams have only a slightly different intensity, in spite of the natural separation beyond the focus (fringes S) and in spite of the separation introduced by the perturbation (fringes M). But on the borders the intensity of the beams becomes very different when the beams deviate and the fringes disappear. This explanation, to have a value in the case of fringes M, requires the variation of the path difference introduced by the perturbation in the width of the slit—which involves the deviation of the beams issued from each slit in the focal plane—to be more rapid than the average variation of the path difference when we pass from one slit to the other (the last involves the deviation of the fringes). For that we have only to admit that the average size of the perturbed regions is less than the distance of the slits.

So the mentioned method does not present any interest; fringes S move as much as fringes M and are not quite so distinct. Besides, we cannot find stable fringes of any use in the experimental arrangement of Michelson.

Summary.—It is pointed out that if a fringe system could be formed having the stationary properties claimed by Messrs. Fürth, Sitte and Appel they would be useless for determining stellar diameters.

Such fringes are not produced by their arrangement. Possible explanations of their seeming experimental success are suggested.

ON A PROPOSED MODIFICATION OF MICHELSON'S STELLAR INTERFEROMETER

J. A. Carroll, M.A., Ph.D.

In *M.N.*, **99**, 141, 1939, Messrs. Fürth, Sitte and Appel describe a modification of Michelson's stellar interferometer, and claim that their modification can be used successfully when, owing to blurring caused by poor seeing, Michelson's fringes would be invisible.

They draw an analogy between a ruled grating illuminated by plane waves and the Michelson fringe system, and argue that as the fringes produced by a grating are unaffected by displacements of the grating in its

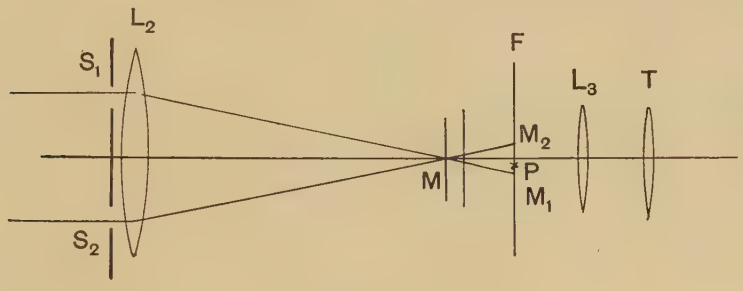

FIG. 1.

own plane the same statement can be made of the secondary system formed from the central part of Michelson's fringes. Their analogy is incomplete, however, as the displacement of Michelson's fringes, in the focal plane of the observing telescope, does not correspond to a simple translatory motion of a grating, but to a translation and a rotation (about an axis parallel to the rulings) of the incident light; thus the secondary system must move in fact through precisely the same number of fringes as does the primary Michelson system. Thus their method is precisely equivalent to Michelson's, and indeed, except they modify their optical train to make it produce merely a magnified system of Michelson fringes, it is inferior to his arrangement. They suggest (§2) using only the central region of the Michelson fringes, and one would expect that their intention was to mask off all but the central few fringes, which are of nearly equal intensity and spacing, and examine the fringe system formed from them by a telescope focussed to infinity. This is not, however, what their arrangement actually does, nor would this be a useful thing to do. In fig. 1 their optical train is sketched.

The optical system, consisting of the lens L_3 and the telescope T placed behind the Michelson fringe system M, allows examination of the pattern formed in any plane in the neighbourhood of M, *e.g.* in the plane F, which is the image in T and L_3 of the focal plane of T. In this plane F are formed

diffraction patterns M_1 and M_2 of the slits S_1, S_2 of like form, but with their centres displaced thus (fig. 2),

At any point P in the plane F interference effects between the overlapping patterns can be observed due to the phase difference in the vibrations from the two slits at that point. This phase difference is due to the difference between the optical paths from S_1 and S_2 to P, and goes through p cycles in going from one minimum of pattern M_1 (or M_2) to the next if the separation of S_1 and S_2 is p times the width of S_1 (or S_2); thus fringes are produced whose separation (angular) is the same as Michelson's, but their visibility will, in general, be poor as the amplitudes of the interfering beams are unequal. If M_1 and M_2 coincide, the amplitudes are equal at all points,

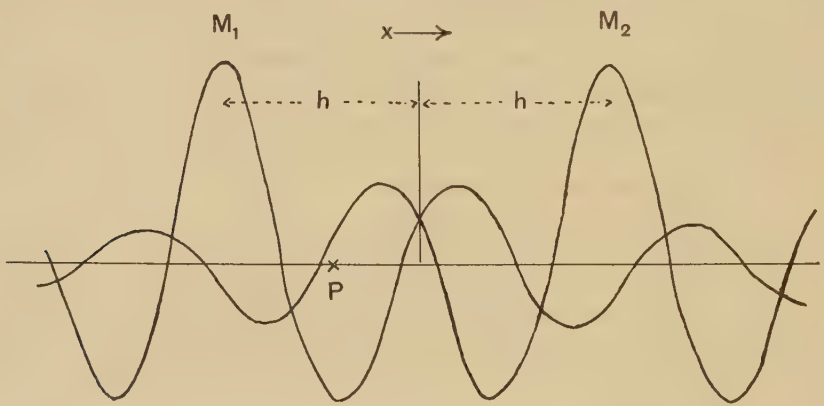

Fig. 2.

these being curves of amplitude of vibration (not intensity) in this plane of the form

$$\frac{\sin a(x-h)}{a(x-h)} \quad \text{and} \quad \frac{\sin a(x+h)}{a(x-h)},$$

and full visibility will be obtained everywhere, the minima being perfectly black. Otherwise fringes will only be observable near the points where $ax \tan ax = ah \tan ah$, and the pattern will consist of the two broad systems M_1 and M_2 crossed at intervals by bands of narrow fringes (see, *e.g.*, fig. 2 of *M.N.*, **99**, 141, 1939). The central maximum (zero path difference) of the narrow fringe system will be approximately midway between the centres of M_1 and M_2 and will move through exactly the same angle (mean) as do the beams incident on S_1 and S_2. Introduction of a phase difference between the incident beams will leave M_1 and M_2 undisplaced but will displace the centre of the narrow system. The system in plane F moves exactly as does the system in plane M, and I have verified this by direct experiment, having set up the arrangement described, but arranging to vary the incident beam. Variation of angle of incidence on S_1, S_2, or the introduction of a phase difference between the beams incident on S_1 and S_2 displaces the fringes M and produces exactly the same displacement of the fringes F; there are thus no fixed fringes of the sort claimed by the authors.

I have also tested experimentally the authors' assertion that the secondary fringes are less liable to disturbance than the Michelson fringes. It is difficult to see any reason for this, as the perturbations that most matter, namely, a change in angle of incidence or in relative phase at incidence, produce displacements. However, direct test fails to substantiate their claim ; any disturbance violent enough to blur the Michelson fringes also blurs the secondary fringes, and their experimental evidence to the contrary is not adequate. Simultaneous observation of the two systems (by interposing a half-silvered mirror near M) is necessary. The disturbance introduced by them is not clearly described, so it is impossible to reproduce it, but the description leads one to suppose a row of bats-wing burners was used, though whether longitudinally or transversely placed to the incident beam is unstated. I find that a hot soldering iron placed below the slits S_1, S_2 produces but little disturbance; the fringes suffer occasional jerky displacements of one or two fringes, and sometimes slower vibrations of the same order are superposed. This does not cause appreciable loss of visibility, as the fringes are stationary for longer periods than they are moving; it would presumably cause some loss of contrast in a long photographic exposure, but not in one of a second or two's duration only. A red-hot iron bar does much the same to both fringe systems, and a narrow gas flame does not do much more. Presumably a fairly uniform sheet of hot air arises from these objects, and this must also have happened over the authors' gas stove. Playing the flame of a Bunsen burner about in front of the slits causes rapid disturbances of the fringes and complete loss of visibility of both systems.

Summary.—Examination of the diffraction and interference problems involved in the modification of Michelson's method proposed by Messrs. Furth, Sitte and Appel shows that stationary fringes cannot be formed in the manner suggested. Experimental test shows that the fringes formed by the proposed arrangement are affected by disturbances in just the same way as are Michelson's.

THE DETERMINATION OF METEOR VELOCITY FROM ZENITH ATTRACTION

Hideo Inouye

(Communicated by R. A. McIntosh)

In a paper in *M.N.*, **96**, 704, 1936, R. A. McIntosh suggested a method of determining the velocity of a meteor stream by telescopic observation of the radiants from two stations widely distributed in latitude. The zenith distances of radiants are not large, and the velocity is deduced from the observed parallactic displacement of the radiants. The writer has conceived a method of obtaining the same result from observations made at only one station.

After attempting to get the numerical value of zenith displacements from observations made on some major showers since 1935 without success, the Leonid shower on 1937 November 14 provided data from which the observed zenith attraction could be determined. From this it was possible to calculate the velocity of the stream.

If observations are made near the meridian we can neglect the influence of diurnal aberration. The daily movement of the radiant may be small during the period of observation. For the sake of simplicity we assume in all cases, neglecting diurnal aberration and daily movement, the following formula :—

$$\tan\frac{\phi_i}{2}=\frac{w-u}{w+u}\tan\frac{z_i}{2} \qquad (i=1,\ 2,\ .\ .\ .),^{*} \qquad (1)$$

where w is the geocentric meteor velocity perturbed by the Earth's attraction, u the unperturbed velocity, z_i the zenith distance of the radiant point, and ϕ_i the zenith displacement at z_i.

The fraction $\dfrac{w-u}{w+u}$ is constant for any one meteor stream, so we write

$$\tan\frac{\vartheta}{2}=\frac{w-u}{w+u}. \qquad (2)$$

Actually we obtain the value of $\Delta\phi=\phi_1-\phi_2$ from two observations, and it follows from elementary trigonometry that

$$\tan\frac{\Delta\phi}{2}=\frac{\tan\frac{\phi_1}{2}-\tan\frac{\phi_2}{2}}{1+\tan\frac{\phi_1}{2}\tan\frac{\phi_2}{2}}=\frac{\tan\frac{\vartheta}{2}\left(\tan\frac{z_1}{2}-\tan\frac{z_2}{2}\right)}{1+\tan^2\frac{\vartheta}{2}\tan\frac{z_1}{2}\tan\frac{z_2}{2}} \qquad (z_1>z_2). \qquad (3)$$

---

* Olivier, *Meteors*, p. 168.

Let

$$\tan\frac{\Delta\phi}{2}=\psi, \qquad \tan\frac{z_1}{2}=a, \qquad \tan\frac{z_2}{2}=b \qquad \text{and} \qquad \tan\frac{\vartheta}{2}=\Theta. \tag{4}$$

Substituting the above (4) in (3) and transforming the formula, we obtain

$$\psi ab\Theta^2-(a-b)\Theta+\psi=0. \tag{5}$$

Evidently Θ is a root of this equation. Solving this, we obtain

$$\Theta=\frac{a-b\pm\{(a-b)^2-4\psi^2ab\}^{\frac{1}{2}}}{2\psi ab}, \tag{6}$$

while

$$w^2=u^2-2gr\int_{\infty}^{r}\frac{d\rho}{\rho^2}=u^2+2gr=u^2+124{\cdot}85, \tag{7}$$

and therefore $w>u>0$ and $0<\Theta<1$ (w and u are expressed in kilometres per second).

If Θ' is another root of the equation we know that $\Theta\Theta'=\frac{1}{ab}$ and $0<ab<1$ (since $0<z_2<z_1\leqq 90°$), from which $\Theta\Theta'>1$; but as $\Theta<1$, $\Theta'>1>\Theta$, and we must choose minus in the formula; thus

$$\Theta=\frac{a-b}{2\psi ab}-\frac{a-b}{2\psi ab}\left(1-\frac{4\psi^2ab}{(a-b)^2}\right)^{\frac{1}{2}}. \tag{8}$$

Expanding the last term by Taylor's series,

$$\Theta=\frac{\psi}{a-b}+\frac{\psi^3ab}{(a-b)^3}+\ldots \tag{9}$$

Expressing the solution with the original symbols,

$$\tan\frac{\vartheta}{2}=\frac{\tan\frac{\Delta\phi}{2}}{\tan\frac{z_1}{2}-\tan\frac{z_2}{2}}+\frac{\tan^3\frac{\Delta\phi}{2}\tan\frac{z_1}{2}\tan\frac{z_2}{2}}{\left(\tan\frac{z_1}{2}-\tan\frac{z_2}{2}\right)^3}+\ldots \tag{10}$$

ϑ is the amount of zenith displacements when the radiant is on the horizon. The geocentric velocities are:

$$u=\sqrt{\frac{gr(1-\sin\vartheta)}{\sin\vartheta}}=\sqrt{\frac{62{\cdot}43(1-\sin\vartheta)}{\sin\vartheta}}\text{km./sec.} \tag{11}$$

$$w=\sqrt{u^2+124{\cdot}85}\text{ km./sec.}=u\frac{1+\tan\frac{\vartheta}{2}}{1-\tan\frac{\vartheta}{2}}. \tag{12}$$

In the accompanying table the writer gives the value of u for some given values of ϑ.

$\tan\frac{\vartheta}{2}$	$\log\tan\frac{\vartheta}{2}$	ϑ	u	
		°	km./sec.	miles/sec.
0·0437	8·6401	5·0	25·7	16·0
·0419	·6223	4·8	26·4	16·3
·0402	·6038	4·6	27·0	16·7
·0384	·5845	4·4	27·6	17·2
·0367	·5643	4·2	28·3	17·6
·0349	·5431	4·0	29·1	18·1
·0332	·5208	3·8	29·9	18·5
·0314	·4973	3·6	30·7	19·1
·0297	·4725	3·4	31·6	19·6
·0279	·4461	3·2	32·8	20·4
0·0262	8·4181	3·0	34·0	21·1
0·0244	8·3881	2·8	35·2	21·9
·0227	·3559	2·6	36·6	22·8
·0210	·3211	2·4	38·1	23·7
·0192	·2883	2·2	39·6	24·6
·0175	·2419	2·0	41·7	25·9
·0157	·1962	1·8	44·0	27·4
·0140	·1450	1·6	47·2	29·2
·0122	·0370	1·4	50·7	31·4
·0105	8·0200	1·2	54·5	33·9
0·00873	7·9409	1·0	59·9	37·0
0·00829	7·9186	0·95	61·3	38·1
·00785	·8951	0·90	63·2	39·2
·00742	·8703	0·85	65·0	40·3
·00698	·8439	0·80	67·1	41·6
·00655	·8159	0·75	69·5	43·1
·00611	·7860	0·70	71·8	44·6
·00567	·7538	0·65	74·5	46·2
·00524	·7190	0·60	78·7	48·1
·00480	·6812	0·55	81·7	50·7
0·00436	7·6398	0·50	85·8	53·3

In 1937 three radiants were determined at the Leonid epoch as follows :—

No.	U.T.	R.A.	Dec.	n	Diameter of Radiant	z
	d h m	°	°		°	°
1	1937 Nov. 13 16 30	149·45	+23·49	6	0·24	63·1
2	13 17 35	149·49	+23·31	7	0·17	50·8
3	13 18 40	149·63	+23·23	5	0·23	38·0

No.	$\Delta\phi$	ϑ	u
	°	°	km./sec.
1–2	0·15	1·07	57·3
2–3	0·13	0·994	59·7
1–3	0·27	1·00	59·5

From the results, 59·5 km./sec. is chosen as the most probable value of u. This seems rather too small a value for the Leonids (theoretical value 71·4 km./sec.). If it is true, we shall be able to explain the slow apparent

angular velocity of telescopic meteors, but there exist some errors in the measurements and the determinations of radiants, due to neglecting the diurnal abberation, daily motion, etc. It will now be necessary to show the approximate accuracy of the velocity.

Differentiating $\tan\frac{\vartheta}{2}=\frac{w-u}{w+u}$, making a few transformations and noticing that $dw=\frac{u}{w}du$ by (7), we obtain

$$du=-\frac{w}{4}\frac{w+u}{w-u}\sec^2\frac{\vartheta}{2}d\vartheta.$$

In the observations from Nos. 1 and 3, we find

$$d\vartheta\fallingdotseq 0\cdot 710 d(\Delta\phi).$$

Comparing the theoretical and observed velocity,

$$du=11\cdot 9 \text{ km./sec.},$$

and the corresponding differences in ϑ and in $\Delta\phi$ are

$$d\vartheta=0^\circ\cdot 0065,$$
$$d(\Delta\phi)=0^\circ\cdot 05.$$

This is the approximate amount of error in the observations : 11·9 km./sec. corresponds to 17 per cent. error in velocity, and for the Leonids at least we can say that if the radiant is determined accurately to 0°·05 we can compute the velocity within 20 per cent. error.

The diurnal aberration can be eliminated by using the first approximate value of u (neglecting the diurnal aberration). The daily motion will be easily eliminated by assuming the amount of mean daily motion.

Summary.—A method is suggested for the determination of meteor velocities from observations made at one station only. A table for the application of the method is given, and an example of the calculation of the velocity of the Leonids is included. The limitations of the accuracy of the method are investigated.

Tokyo College for Physics and Chemistry,
Tokyo :
1939 *June* 24.

MICROMETRICAL MEASURES OF DOUBLE STARS

R. v. d. R. Woolley

(Communicated by the Director, Cambridge University Observatory)

The following measures have been made with the 12-inch Northumberland refractor (N) and the 8-inch Thorrowgood refractor (T) as indicated, during the period 1937 June to 1939 August. The stars are described by their number in ADS, *i.e.* Aitken's *New General Catalogue of Double Stars.*

ADS	Name	Date 1900 +	Position Angle	Separation	No. of Nights	Telescope
			°	″		
61	Σ 3062	37·98	78·9	0·94	1	T
		38·80	85·6	0·92	4	N
263	Kr 4	37·98	182·0	2·25	1	T
434	OΣ 12	37·92	166·7	0·65	3	T
		38·84	166·3	0·69	2	N
671	Σ 60	37·94	278·6	8·70	2	T
1105	Σ 115	37·83	142·1	1·11	1	T
		38·93	142·1	0·99	2	N
1438	Σ 162	37·99	208·9	1·87	1	T
		39·00	207·8	1·78	2	N
1598	β 513	38·00	264·0	0·87	7	T
1659	OΣ 37	37·99	209·4	1·20	1	T
1860	Σ 262	AB 37·99	244·9	2·46	5	T
		AC 37·98	116·1	7·17	3	T
		BC 37·98	101·5	9·24	3	T
2204	Σ 312	38·02	26·8	2·82	2	T
2377	OΣ 50	37·99	188·2	1·30	1	T
2628	β 533	39·12	45·5	0·98	2	N
2867	OΣ 67	38·02	42·3	1·64	1	T
2963	Σ 460	37·98	75·9	0·90	5	T
3172	OΣ 80	38·18	167·0	0·69	1	N
3358	Σ 566	38·13	274·6	1·28	1	T
		39·07	267·0	1·20	4	N

ADS	Name	Date 1900 +	Position Angle	Separation	No. of Nights	Telescope
			°	″		
3672	OΣ 95	38·14	315·9	0·90	2	T
3711	OΣ 98	38·16	111·7	1·06	2	T
		39·06	106·8	1·02	4	N
3734	Σ 644	38·16	222·5	1·73	3	T
		39·14	221·1	1·56	1	N
4371	β 560	38·07	145·1	1·17	3	T
4376	Σ 3115	38·00	11·3	1·11	4	T
5400	Σ 948	AB 38·00	100·4	1·86	4	T
		39·18	100·2	1·58	5	N
		AC 38·00	306·9	8·69	4	T
		39·21	308·7	8·55	4	N
		BC 38·00	302·3	10·30	4	T
		39·19	302·4	10·30	3	N
5746	Σ 1009	39·03	151·2	3·34	1	N
6028	Σ 1051	38·15	285·2	1·22	1	T
6650	Σ 1196	AB 38·24	100·2	0·90	4	N
		39·28	93·8	0·92	2	N
		AC 38·24	101·0	6·43	4	N
		39·28	100·8	6·56	2	N
		BC 38·24	101·6	5·58	4	N
		39·28	100·9	5·50	2	N
7067	Σ 1280	38·07	57·5	3·46	3	T
7071	Σ 1291	38·09	320·4	1·60	2	T
		38·24	320·6	1·52	4	N
7284	Σ 3121	38·23	24·6	0·80	2	N
7286	Σ 1333	38·09	44·0	1·86	1	T
		38·24	47·0	1·79	4	N
7307	Σ 1338	38·09	199·5	1·52	1	T
7545	OΣ 208	38·20	350·8	0·61	2	N
		39·30	350·0	0·66	1	N
7704	OΣ 215	38·26	193·9	1·19	4	N
7929	OΣ 229	38·28	301·2	0·94	1	N
8249	Σ 1559	38·17	323·7	2·18	1	T
8446	Σ 1606	38·28	314·7	1·02	1	N

ADS	Name	Date 1900 +	Position Angle	Separation	No. of Nights	Telescope
			°	″		
8539	Σ 1639	38·26	333·9	1·14	5	N
		39·32	332·0	1·10	2	N
8974	Σ 1768	38·42	114·9	1·66	3	N
		39·34	114·0	1·82	1	N
9229	Σ 1834	38·39	98·8	0·94	1	N
9343	Σ 1865	38·40	314·6	1·13	6	N
9389	Σ 1884	38·45	55·4	1·77	3	N
9425	OΣ 288	38·42	182·7	1·65	3	N
9494	Σ 1909	38·42	247·0	2·53	5	N
		39·46	248·4	2·47	3	N
9626	Σ 1938	38·50	35·4	1·54	6	N
		38·57	36·7	1·52	1	T
		39·53	34·9	1·66	3	N
9909	Σ 1998	AB 37·58	27·6	1·34	2	T
		AC 37·58	55·0	10·14	2	T
		BC 37·58	63·3	7·38	2	T
10052	Σ 2054	38·55	357·8	1·19	3	N
		38·57	359·5	1·13	1	T
10279	Σ 2118	37·58	75·2	0·89	3	T
10345	Σ 2130	38·57	102·5	2·27	1	T
		38·61	102·9	2·02	5	N
		39·55	100·8	2·06	5	N
10598	Σ 2173	37·58	162·4	1·04	3	T
		38·70	161·5	1·04	2	N
10850	OΣ 338	39·16	4·0	0·86	2	N
11005	Σ 2262	37·58	265·5	1·95	2	T
11897	Σ 2438	37·58	15·1	0·76	2	T
		38·66	10·3	0·66	4	N
12239	OΣ 371	38·65	156·5	0·78	5	N
12296	Σ 2509	38·76	333·9	1·35	4	N
12447	Σ 2525	37·68	298·8	1·42	5	T
		38·65	298·4	1·25	3	N
12851	OΣ 384	38·64	194·3	1·03	3	N

ADS	Name	Date 1900 +	Position Angle	Separation	No. of Nights	Telescope
			°	″		
12880	Σ 2579	37·62	261·3	1·98	5	T
		38·64	261·7	1·82	4	N
		39·60	261·1	1·98	3	N
12962	Σ 2583	38·71	113·1	1·49	4	N
13277	OΣ 395	38·66	110·6	0·83	4	N
13312	Σ 2624	37·67	175·6	2·05	3	T
13329	Σ 2626	37·71	123·4	1·22	3	T
13572	OΣ 403	37·73	174·2	0·89	1	T
		39·62	173·5	0·86	1	N
14126	OΣ 410	37·66	13·0	0·88	3	T
		38·66	8·6	0·77	3	N
14158	Σ 2716	39·16	46·4	2·62	2	N
14196	β 152	37·73	93·3	0·90	1	T
		38·77	93·2	0·91	3	N
14296	OΣ 413	37·74	45·2	0·78	4	T
		38·66	37·5	0·77	4	N
14421	OΣ 418	39·14	285·4	1·19	2	N
14504	Σ 2741	38·74	29·3	1·94	5	N
14578	Hu 959	37·78	155·8	1·56	3	T
14645	Σ 2760	38·76	233·6	2·23	4	N
14916	Σ 2801	37·78	272·6	1·96	3	T
15270	Σ 2822	38·78	219·6	0·64	5	N
15407	Σ 2843	37·80	142·0	1·80	4	T
		38·66	141·4	1·77	4	N
15467	OΣ 457	38·64	254·5	1·27	1	N
16298	Σ 2948	37·76	3·5	2·47	1	T
16317	Σ 2950	37·80	300·3	1·92	3	T
		38·67	300·3	1·83	3	N
		39·62	229·2	1·89	2	N
16371	Σ 2963	37·82	356·5	2·15	3	T
16666	Σ 3001	37·84	209·0	2·92	3	T
		38·94	207·8	2·66	4	N

ADS	Name	Date 1900 +	Position Angle	Separation	No. of Nights	Telescope
			°	″		
16836	β 720	38·73	221·6	0·55	2	N
16877	OΣ 500	37·91	337·3	0·69	3	T
		38·72	340·2	0·60	1	N
16957	AGC 14	37·89	208·6	1·19	1	T
17149	Σ 3050	38·94	244·5	1·67	3	N

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Unless otherwise indicated, the donor is the author or the Institution concerned.

An asterisk (*) indicates that the work is an excerpt.
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Belorizky (D.) :
*Sur la stabilité dans le problème des trois corps. 8vo. Paris, 1938

Bergstrand (Östen) :
†Festskrift tillägnad Östen Bergstrand den 1 September 1938.
8vo. Uppsala, 1938

British Association for the Advancement of Science :
——: The Geocentric Direction Cosines of Seismological Observatories. Compiled by L. J. Comrie. With an Introduction by Harold Jeffreys. (*Gray-Milne Trust, Oxford University.*) 8vo. London, 1938

——: Tables for converting Geographic into Geocentric Angular Distances, by K. E. Bullen. With an Introduction by Harold Jeffreys. (*Gray-Milne Trust, Oxford University.*) 8vo. Newport, I.o.W., 1938

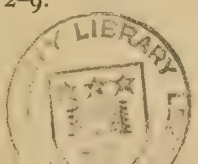
Cambridge University :
Calendar for the Year 1938–1939. (*Cambridge University Press.*) 8vo. Cambridge, 1938

Corlin (Axel) :
——: *How Larger Bodies may be built up out of Small Particles in Interstellar Space. 8vo. Berlin, 1938

——: *On the Origin of Comets. 8vo. Uppsala, 1938

Dingle (Herbert) :
Through Science to Philosophy. 8vo. Oxford, 1937

†Discovery :
New Series. Vol. I, Nos. 2–9. 8vo. Cambridge, 1938



Edinburgh, The Astronomical Society of :
Publications. No. 1. 8vo. Edinburgh, 1938
No. 1. The Depths of Space, by Sir James Jeans. (The Lorimer Lecture, 1938.)

Fabry (Charles) :
——: Jubilé scientifique de M. Charles Fabry célébré à la Sorbonne le 3 décembre 1937. 4to. Paris, 1938

——: Œuvres choisies publiées à l'occasion de son Jubilé Scientifique. 8vo. Paris, 1938

Hughes (A. J.) :
The Book of the Sextant. With Ancient and Modern Instruments of Navigation. 8vo. Glasgow, 1938

Jones (H. Spencer) :
——: The Atmospheres of the Planets. (The Norman Lockyer Lecture, 1938.) 8vo. London, 1938
——: *The Measurement of Time. 8vo. Cambridge, 1938

Kepler (Johannes) :
†Gesammelte Werke. Herausgegeben im Auftrag der deutschen Forschungsgemeinschaft und der Bayerischen Akademie der Wissenschaften. Unter der Leitung von Walther von Dyck† und Max Caspar. Band I. 4to. München, 1938
Band I. Mysterium cosmographicum de stella nova. Herausgegeben von Max Caspar.

Khan (Mohamed A. R.) :
*On the Meteoric Origin of the Black Stone of the Ka'bah. 8vo. Northfield, Minn., 1938

Kyoto Imperial University, Institute for Astrophysics :
*Contributions. No. 1. 8vo. Kyoto, 1938

McCaw (G. T.) :
*Rapport sur les latitudes, longitudes et azimuts et sur les applications géodésiques de la télégraphie sans fil. 4to. Paris, 1938

Myres (John L.) :
*John Knight Fotheringham (1874–1936). (*Oxford University Press.*) 8vo. London, 1938

Paris, Caisse Nationale de la Recherche Scientifique : Service de Recherche d'Astrophysique :
Annales d'Astrophysique. Année 1, No. 3, Juillet 1938. 4to. Paris, 1938

Volta (Luigi) :
*Guiseppe Ruggero Boscovitch. 8vo. Roma, 1938

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Adams (Walter S.) :
*George Ellery Hale, 1868–1938. 8vo. Chicago, 1938

Berlin, Preussische Akademie der Wissenschaften :
†Geschichte des Fixsternhimmels, enthaltend die Sternörter der Kataloge des 18, und 19. Jahrhunderts. Abteilung II. Der südliche Sternhimmel. Band 3. 4to. Karlsruhe, 1938
Band 3. 2^h Rektaszension.

Chandrasekhar (S.) :
†An Introduction to the Study of Stellar Structure. (Astrophysical Monographs Series.) 8vo. Chicago, 1938

da Costa Lobo (F. M.) :
A acção diplomática dos portugueses nos séculos XV e XVI, destinada à realização de descobertas e conquistas. (I congresso da história da expansão portuguesa no mundo 3ª secção.) 8vo. Lisboa, 1937

Sir Howard Grubb, Parsons & Company :
Publication No. 12. 4to. Newcastle-upon-Tyne, 1938
No. 12. *74-inch Reflecting Telescope of the Radcliffe Observatory, Pretoria.

Klepesta (Josef) :
†Spectral Atlas of Bright Stars of the Northern and Southern Hemisphere, containing all stars brighter than 5·1 visual magnitude, classified according to the Henry Draper Catalogue. fol. Praha, 1937

Lacchini (Giovanni Battista) :
——: *Osservazioni di occultazioni di stelle (1936–1937–1938). 8vo. Roma, 1938

——: *Osservazioni di stelle doppie (1937–1938). 8vo. Roma, 1938

Leonard (Frederick C.) :
*The International Astronomical Union Meeting at Stockholm, Sweden, 1938 August 3–10. 8vo. Northfield, 1938

Liége, Société Astronomique :
Bulletin mensuel. 1 année, numéro 1. 4to. Liége, 1939

Paris, Institut de France, Académie des Sciences :
Notices et discours. Tome 1. 1924–1936. 4to. Paris, 1937

Poggendorff's Biographisch-literarisches Handwörterbuch :
†Band VI: 1923 bis 1931. III Teil, L–R. crn. 8vo. Berlin, 1938

Prague, National Observatory of the Czechslovak Republic :
Travaux dédiés à Dr. František Nušl, Directeur de l'Observatoire National de Praha et Professeur de l'Université de Charles VI, pour son soixante-dixième anniversaire, le 3 décembre 1937. 8vo. Praha, 1938

Russell (Henry Norris) :
*The Atmospheres of the Planets. 8vo. Washington, 1936

Waldmeier (M.) :
——: *Sonneneruptionen und ihr Einfluss auf die Ausbreitung elektromagnetischer Wellen. 8vo. *s.l.*, 1938

——: *Über die Struktur der Sonnenflecken. 8vo. *s.l.*, 1938

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Alter (Dinsmore) :
*A periodogram investigation of short-period sunspot cycles.
4to. Washington, 1938

Csillagászati Lapok : Astronomische Blätter: Zeitschrift der astronomischen Abteilung des Kön. Ung. Naturwissenschaftiches Vereins, unter Mitwirkung von Prof. J. Wodetzky, redigiert von L. Detre und K. Lassovsky. Jahrgang 1, Heft 1, 2. 8vo. Budapest, 1938

Eagle (Albert) :
——: *Difficulties underlying the Einstein-Eddington conception of curved space. 8vo. London, 1938
——: *A criticism of the special theory of relativity. 8vo. London, 1938

Forschungen und Fortschritte :
Nachrichtenblatt der Deutschen Wissenschaft und Technik. Gegründet und mit Unterstützung der deutschen wissenschaftlichen Körperschaften herausgegeben von Karl Kerkhof. Jahrgang 15, Nr. 1–6.
4to. Leipzig, 1939

Jena Universität :
Beiträge zur Geschichte der Universität Jena. Heft 7. 8vo. Jena, 1937
Heft. 7. Otto Knopf, Die Astronomie an der Universität Jena von der Gründung der Universität im Jahre 1558 bis zur Empflichtung des Verfassers im Jahre 1927.

Kepler (Johannes) :
†Gesammelte Werke. Herausgegeben im Auftrag der deutschen Forschungsgemeinschaft und der Bayerischen Akademie der Wissenschaften. Unter der Leitung von Walther von Dyck † und Max Caspar. Band II.
4to. München, 1939
Band II. Astronomiae pars optica. Herausgegeben von Franz Hammer.

Lundmark (Knut) :

*Was the Crab Nebula formed by a Supernova in 1054 A.D.?
4to. Uppsala, 1938

MacPike (Eugene Fairfield) :

Dr. Edmond Halley (1656–1742). A bibliographical guide to his life and work arranged chronologically. Preceded by a list of sources, including references to the history of the Halley family. 8vo. London, 1939

Minneapolis, University of Minnesota, Astronomical Observatory :

Publications. Vol. II, Nos. 5, 6. 8vo. Minneapolis, 1938

No. 5. W. J. Luyten, Bruce Proper Motion Survey. I. First Report.
No. 6. W. J. Luyten, Bruce Proper Motion Survey. II. A Catalogue of 4350 Variable Stars found with the Blink Microscope.

Odessa, Premier Observatoire Astronomique :

Bulletin. 1939 No. 1. 8vo. Odessa, 1938

Payne-Gaposchkin (Cecilia) and Sergei Gaposchkin :

†Variable Stars. (Harvard Observatory Monographs, No. 5.)
8vo. Cambridge, 1938

Quito, Observatorio Astronomico y Meteorologico :

Boletin Meteorologico. 1937 Jul.–Dic. y resumen del año.
fol. Quito, 1938

Schalén (Carl) :

*Über die Bedeutung des Strahlungsdruckes und der Gravitation für die Verteilung interstellarer Materie. 8vo. Berlin, 1939

Siedentopf (H.) :

*Über Körnigkeit, Dichteschwankungen und Vergrösserungsfähigkeit photographischer Negative. 4to. Leipzig, 1937

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Athens, Observatoire National :
Annales. Tome 12. 4to. Athènes, 1932

Bern, Schweizerische Geodätische Kommission :
Astronomisch-geodätische Arbeiten in der Schweiz. Band 20.
4to. Bern, 1939
Band 20. Das astronomische Nivellement im Meridian des St. Gotthard. II. Die berechneten Geoiderhebungen und der Verlauf des Geoidschnittes, bearbeitet von Th. Niethammer.

Corlin (Axel) :
*On the building up of larger bodies from small particles in interstellar space.
8vo. Berlin, 1939

Kyoto Imperial University, Institute for Astrophysics :
*Contributions. No. 2. 8vo. Kyoto, 1938
No. 2. S. Miyamoto, On the Balmer Emission of the Planetary Nebulæ.

London, British Astronomical Association :
Catalogue of the Library of the British Astronomical Association. Compiled to 1936 July 31. 8vo. London, 1936

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Cambridge, Solar Physics Observatory:

†Atlas of Spectra of Nova Herculis 1934. By F. J. M. Stratton and W. H. Manning. fol. Cambridge, 1939

Gleissberg (W.):

*On the Minimum Integral in the Theory of the Interior of a Star. 4to. Istanbul, 1939

Sir Howard Grubb, Parsons & Company:

Publication No. 13. 4to. Newcastle-upon-Tyne, 1938

No. 13. *Solar Telescope at Oxford University Observatory.

Haas (Walter H.):

——: *Jupiter in 1936. 8vo. Northfield, 1937
——: *A method of investigating lunar changes. 8vo. Northfield, 1937
——: *Saturn in 1936. 8vo. San Francisco, 1937
——: *Mercury and Venus in 1936. 8vo. Toronto, 1937
——: *The problem of lunar changes. 8vo. Toronto, 1938

Hamburger Sternwarte in Bergedorf:

——: Spektral-Durchmusterung von Milchstrassenfeldern, enthaltend für die Sterne bis zur photographischen Grösse 13·5 die Spektren und die Grössen nach Aufnahmen mit dem Lippert-Astrographen der Hamburger Sternwarte in Bergedorf. Von A. A. Wachmann. Teil I. 4to. Hamburg-Bergedorf, 1939

——: Viertes Bergedorfer Sternverzeichnis 1950·0 enthaltend die mittleren Örter von 492 Zusatzsternen zum Drittenfundamentalkatalog (FK_3) des Berliner Astronomischen Jahrbuchs, nach Beobachtungen am Repsoldschen 19 cm.-Meridiankreis in den Jahren 1935 bis 1938. Von F. Dolberg und J. Larink. 4to. Hamburg-Bergedorf, 1939

Hartner (Willy) :
*The Pseudoplanetary Nodes of the Moon's Orbit in Hindu and Islamic Iconographies. 4to. *s.l.*, 1938

Helsingfors, Isostatic Institute of the International Association of Geodesy :
Publications. Nos. 1–5. 8vo. Helsinki, 1938–1939

International Astronomical Union :
Transactions. Vol. VI. 4to. Cambridge, 1939

International Geodetic and Geophysical Union : Association de Géodésie :
Programme provisoire de la septième assemblée générale à Washington du 3 au 15 septembre 1939. 8vo. Toulouse, 1939

Järnefelt (G.) :
——: *Bemerkungen über das Spektrum von Nova Herculis 1934 im März 1935. 8vo. Helsinki, 1937
——: *Zeitpunkt des Eintritts der partiellen Phase von Zeta Aurigæ im April 1937. 8vo. Helsinki, 1939
——: *Zur relativistischen Perihilbewegung der Planetenbahnen. 8vo. Helsinki, 1939

Leningrad, Academy of Sciences :
Total Solar Eclipse of June 19, 1936. Reports of Soviet Expeditions. I. 8vo. Leningrad, 1939

Leningrad, Institut de Métrologie de l'U.R.S.S. :
La calorie 20° et son rapport à l'unité absolue. 8vo. Leningrad, 1939
Etude sur les interférences lumineuses en métrologie. 8vo. Leningrad, 1939
Sur l'établissement des étalons des unités magnétiques. 8vo. Leningrad, 1939
Etude de règles en platine iridié No. 28, No. 11, II 4, M 20°. 8vo. Leningrad, 1939

Lima, Sociedad de Ingenieros del Peru :
Informaciones y Memorias. Vol. XL, No. 3. 8vo. Lima, 1939

London, The Physical Society :
†Reports on Progress in Physics. Vols. IV, V. 8vo. London, 1938–39

Lourenço Marques, Missão Hidrográfica da Colónia de Moçambique :
Relatório do Levantamento Magnético da Baía de Lourenço Marques, por Raúl Ferreira de Carvalho. 1.° tenente. 23 de Março de 1938. 4to. Lourenço Marques, 1939

Lourenço Marques, Repartição de Estatística :
Apenso ao boletim económico e ēstatístico. Ano III. Julho a Dezembro de 1936—Nos. 7 a 12. Boletim mensal das observações meteorológicas feitas nos postos da Colónia. Organizado pelo Observatório Campos Rodrigues. 4to. Lourenço Marques, 1938

McIntosh (R. A.) :
——: *Determination of the real paths of fireballs. 8vo. Toronto, 1938
——: *Meteor rates in the Southern Hemisphere. 8vo. Northfield, Minn., 1938

Malikov (M. F.) :
Sur la définition des unités électriques et magnétiques dans le système électro-magnétique absolu MKS (μ). (Russian and French.)
8vo. Leningrad, 1939

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†Diario y iuyzio del grande Cometa que nuevamente nos ha aparecido hazia Occidente alas cinco y media hora dela tarde alos 8. dias de Noviembre año de 1577. 8vo. Barcelona, 1578

Milne (John) :
†Earthquakes and other Earth movements. New edition. Revised and rewritten by A. W. Lee. 8vo. London, 1939

Mitchell (S. A.) :
*Discoveries from Solar Eclipse Expeditions. 8vo. Washington, 1938

Nilsson (Gerhard) :
Erklärung eines Phänomens der statischen Elektrizität. 1. Auflage.
8vo. Stockholm, 1938

Odessa, Observatoire Astronomique de l'Université :
Travaux. Tomes 1, 2. 8vo. Odessa, 1935–1937

Oppolzer (Theodor von) :
Canon der Finsternisse: Introduction. Translated by Valerie Baker and edited by M. Davidson and D. H. Sadler.
(*British Astronomical Association.*) typescript, 1939

Paduanius (Joannes) :
†Opus de stellis crinitis deque earum variis singillatim significationibus, præcipuè eius quæ se ostendit in fine anni 1577. 4to. Veronæ, 1578

Paris, Comité National Français de Géodésie et Géophysique :
Two brochures. 8vo. Paris, 1936–1938

P. Lejay, Exploration gravimétrique de l'extrême-orient.
P. Lejay, Exploration gravimétrique des Etats du Levant sous mandat français.

Perelli (Anselmo) :
Osservazioni meccaniche sopra un suo circolo ossia orologio astronomico intorno al giro del sole, e moto della terra. Con un modo di trovare quanti gradi di Longitudine possa aver oltrepassato un Bastimento in mare. Ed alcune riflessioni sopra il Sistema di Copernico dell'istesso Autore.
(*G. H. Wyatt.*) 8vo. Venezia, 1794

Potsdam, Preussisches Geodätisches Institut :
Zeitsignale. 1939 Januar–Mai. 4to. Potsdam, 1939

See (T. J. J.) :
Wave-Theory. Discovery of the Cause of Molecular Forces. Books I, II, III. 4to. Lynn (Mass.), 1938–1939

Staples (H. A.) :
Cosmic Machinery in an electro-magnetic Universe. 8vo. London, 1939

Störmer (Carl) :
——: *Photographic Measurements of the Great Aurora of January 25–26, 1938. 8vo. London, 1938
——: *Photographische Höhenmessungen und Spektra des grossen Nordlichtes vom 25 bis 26 Januar 1938. 4to. Berlin, 1938
——: *Blue Sunlit Aurora Rays and their Spectrum. 8vo. London, 1938
——: *Blue Auroral Rays situated in the Sunlit Part of the Atmosphere. 8vo. Baltimore, 1939

Tiflis, Institut Géophysique, Station Séismique Centrale :
Bulletin trimestriel. No. 4. 8vo. Tbilissi, 1939

Tikhodeev (P. M.) :
Sur la définition de l'unité photométrique fomdamentale en vue de l'adoption d'un nouvel étalon de lumière. (Russian and French.) (*Leningrad, Institut de Métrologie.*) 8vo. Leningrad, 1939

Tokyo Imperial University, Department of Astronomy :
*Report of the Expedition sent from the Department of Astronomy in the Tokyo Imperial University for the Observation of the Total Solar Eclipse of June 19, 1936. Parts I, II, III. 4to. Tokyo, 1938

Wellington (N.Z.), New Zealand Astronomical Society :
Star Colour Section. Memoirs. Nos. 1–4. fcap. typescript, 1939

Willis (E.) :
Tables for the Computation of Meteor Orbits. sm. 8vo. London, 1939

Zinner (Ernst) :
Die ältesten Räderuhren und modernen Sonnenuhren: Forschungen über den Ursprung der modernen Wissenschaft. 8vo. Bamberg, 1939

Zonn (W.) :
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LIST OF ADDITIONS

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Jahrgang 2, Heft 2. 8vo. Budapest, 1939

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Massachusetts Institute of Technology :

†Wavelength Tables . . . measured and compiled under the direction of George R. Harrison. fol. New York, 1939

Nautical Almanac Office :

Planetary Co-ordinates for the Years 1940–1960, referred to the Equinox of 1950·0. Prepared by H.M. Nautical Almanac Office.
4to. London, 1939

Pulkovo Observatory :

Two articles in Russian, with English Summaries, on the Total Solar Eclipse of 1941.

1. A. A. Michailov, Total Solar Eclipse of 1941 September 21.
2. T. V. Pokrovskaya, Meteorological Conditions for observing the Solar Eclipse of 1941 September 21 in the Path of Totality.

Tillotson (Ernest) :

PcP and *ScS*. 8vo. Berkeley, Cal., 1939

Washburn Observatory, Madison :

Madison Catalogue of 2786 Stars for the Epoch 1910, from Meridian Observations by Albert S. Flint. Reductions by Arthur J. Roy. (*Carnegie Institution of Washington.*) 4to. Washington, 1939

Washington, National Geographic Society :

Contributed Technical Papers. Solar Eclipse Series, No. 1. (*National Geographic Society.*) 8vo. Washington, 1939

No. 1. National Geographic Society : U.S. Navy Solar Eclipse Expedition of 1937 to Canton Island.

INDEX

PAGE

Adelaide Observatory, Report of the proceedings of 360
Annual General Meeting, Report of the proceedings of the 279
Appel, H. P., R. Fürth, K. Sitte and, A modification of the Michelson interferometer method for the determination of stellar diameters 141
Archenhold, G. H., The influence of the variability of the mean latitude of sunspots on the recurrence tendency of magnetic disturbances 723
Armagh Observatory, Report of the proceedings of 343
Associates elected 537
Auditors of the Treasurer's accounts for 1938, Appointment of 59
—— Report of the 289
Auluck, F. C., The theory of pressure ionization and the constitution of the white dwarf stars 239

Baillaud, E. B., Posthumous work of, presented to the Society 2
Baldwin, J. M., Occultations of stars by the moon observed at Melbourne Observatory in 1937 276
Barker, Robert, Report of his observatory (Cheshunt) 364
Brown, E. W., Bequest to the Society 2
Brown, F. G., The inclinations of the spiral nebulæ to the line of sight 14
—— The distribution of the position-angles of the extra-galactic nebulæ in Horologium 534
Brück, H. A., A photoelectric recording photometer for the solar spectrum 607
Bruna, P. P., The dependence of the solar velocity on the distance from the plane of the Milky Way 248

Cambridge Observatory, Report of the proceedings of the 344
Cambridge University, Solar Physics Observatory, Report of the proceedings of the ... 344
Camm, G. L., A study of galactic rotation, based on the velocities of the planetary nebulæ 71
Canberra, Commonwealth Solar Observatory, Report of the proceedings of the ... 360
Candidates proposed 1, 59, 140, 279, 437, 477, 537
Cape of Good Hope, Royal Observatory, Stellar parallaxes (Tenth list) 52
—— —— Errata 58
—— Report of the proceedings of the 340
—— Occultations observed in 1938 471
Carroll, J. A., On a proposed modification of Michelson's stellar interferometer ... 735
Chandrasekhar, S., The minimum central temperature of a gaseous star 673
Comets, Council report on, in 1938, Rev. M. Davidson 409
Cosmic Evolution : The fission of rotating bodies, K. E. Edgeworth 272
—— On the fission of a rotating fluid mass, R. A. Lyttleton 567
—— On the origin of the solar system, W. J. Luyten 692

Douglas, A. Vibert, J. Stuart Foster and, Stark effect in B stars 150
Durham University Observatory, Report of the proceedings of the 346
Dynamical Astronomy : On the rotation of the planets, R. A. Lyttleton 181
—— The rotation of the earth, and the secular accelerations of the sun, moon and planets, H. Spencer Jones 541
Dyson, Sir Frank Watson, Death of: Council resolution 579

Earth, Rotation of the : The rotation of the earth, and the secular accelerations of the sun, moon and planets, H. Spencer Jones 541
Eddington, Sir A. S., Star models with variable polytropic index 4
—— The hydrogen content of white dwarf stars in relation to stellar evolution 595
Edgeworth, K. E., The fission of rotating bodies 272
Edinburgh, Royal Observatory, Report of the proceedings of the 339

PAGE

Edmondson, F. K., Stellar kinematics and mean parallaxes (Second paper) 525
Errata 58, 277, 535
Errors, Theory of: The law of error and the combination of observations, H. R. Hulme and L. S. T. Symms 642
—— The law of error in the Greenwich variation of latitude observations, Harold Jeffreys 703
Evans, D. S., The Stark effect of hydrogen and centre-to-limb variations in the contours of $H\beta$, $H\gamma$ and $H\delta$ 17
Evershed, J., New measures of the wave-lengths of the calcium lines K and H 120
—— Note on the Zeeman effect in sunspot spectra 217
—— Report of his observatory (Ewhurst) 364
—— Measures of the relative shifts of the line 5250·218 and neighbouring lines in Mount Wilson solar magnetic field spectra 438
Expansion of the Universe, Joint meeting with the Physical Society to discuss the ... 3

Fellows elected 1, 139, 279, 437, 477, 537, 579
Fletcher, Alan, Tables of the two chief Laplace coefficients 259
Foster, J. Stuart, and A. Vibert Douglas, Stark effect in B stars 150
Fürth, R., K. Sitte and H. P. Appel, A modification of the Michelson interferometer method for the determination of stellar diameters 141

Galactic Rotation: A study of galactic rotation, based on the velocities of the planetary nebulæ, G. L. Camm 71
—— On the interpretation of the spectroscopically observed rotations of galaxies, Erik Holmberg 650
Geophysical Discussions, Dates of, rearranged 60
George Darwin Lecture, 1939: see Lyot, Bernard.
Gifts to the general funds and property of the Society 290
Glasgow, University Observatory, Report of the proceedings of the 346
Gleissberg, W., A theorem on the pressure in the interior of a star 188
Gold Medal of the Society, The, awarded to M. Bernard Lyot for his observations and photography of the solar corona in the absence of a total solar eclipse 140
—— Address of the President (Professor H. C. Plummer), on presenting the Gold Medal to M. Bernard Lyot 538
Goodridge Bequest 292
Greenwich, Royal Observatory, Stellar parallaxes 49
—— —— Erratum 277
—— Report of the proceedings of the 330
Grove-Hills Special Fund 291

Hargreaves, F. J., An improved liquid-filled prism 127
Haughton, J. L., Observations of occultations made at Teddington during 1937 ... 136
—— Report of his observatory (Teddington) 365
—— Occultations observed at Teddington in 1938 701
Heath, M. B. B., Report of his observatory (Kingsteignton) 365
Helwan Observatory, Egypt, Report of the proceedings of 355
Herschel, Sir William, Artaut portrait of, presented to the Society by Rev. Sir John Herschel 3
—— —— Society's duplicate copy presented to the Royal Observatory, Greenwich ... 280
Holborn, F. M., Report of his observatory (Streatham Hill) 365
Holmberg, Erik, On the interpretation of the spectroscopically observed rotations of galaxies 650
Hulme, H. R., A comparison of the declinations of the Boss General Catalogue with those derived from the observations with the Cookson floating telescope to determine the variation of the latitude at Greenwich during the years 1911–1936 199
—— Preliminary values of the variation of latitude at Greenwich during 1936–1938, together with an account of the new observing programme 202
—— On the motion of solar prominences and streamers 634
—— Note on the integration of the equation of the formation of absorption lines ... 730
Hulme, H. R., and L. S. T. Symms, The law of error and the combination of observations 642
Hyderabad, Nizamiah Observatory, Report of the proceedings of the 356
—— Occultations of stars by the Moon, observed during the year 1938 575

PAGE

Inouye, Hideo, The determination of meteor velocity from zenith attraction 738
Instruments and Appliances, etc. : An improved liquid-filled prism, F. J. Hargreaves 127
—— The Oxford solar telescope and Hartmann tests of its performance, H. H. Plaskett 219
—— A simple wedge-photometer for observing bright chromospheric eruptions with a spectroheliоscope, H. W. Newton 463
—— A photoelectric recording photometer for the solar spectrum, H. A. Brück ... 607
—— On some observations made with a modified Pickering polarigraph, Yngve Öhman 624
—— A new projection micrometer machine for stellar spectrograms, R. O. Redman 686
Investments 288

Jeffreys, Harold, The constant of nutation 206
—— Seismological tables (Council report on the progress of astronomy) 397
—— The law of error in the Greenwich variation of latitude observations 703
Johannesburg, Union Observatory, Report of the proceedings of the 358
Jones, H. Spencer, The tidal effect on the variation of latitude at Greenwich 196
—— The determination of the constant of nutation from the Greenwich latitude variations (Second paper) 211
—— Some problems of meridian astronomy (Presidential address) 424
—— The rotation of the earth, and the secular accelerations of the sun, moon and planets 541
Jupiter : On the chemical nature of the colouration of Jupiter's cloud forms, Rupert Wildt 616

K-term, The "southern stream" and the, P. Samuels Lall 42
Kienle, Hans Georg, elected an Associate of the Society 537
Kodaikanal Observatory, Report of the proceedings of 356
Kopal, Zdeněk, On the density condensations of Cepheid Variables 33
—— Remarks on the equilibrium of distorted polytropes 266

Lacroute, P., A modification of the Michelson interferometer method for the determination of stellar diameters 733
Lall, P. Samuels, The "southern stream" and the *K*-term 42
Laplace Coefficients, Tables of the two chief, Alan Fletcher 259
Latitude Variation : The tidal effect on the variation of latitude at Greenwich, H. Spencer Jones 196
—— A comparison of the declinations of the Boss General Catalogue with those derived from the observations with the Cookson floating telescope to determine the variation of the latitude at Greenwich during the years 1911–1936, H. R. Hulme 199
—— Preliminary values of the variation of latitude at Greenwich during 1936–1938, together with an account of the new observing programme, H. R. Hulme ... 202
—— The determination of the constant of nutation from the Greenwich latitude variations (Second paper), H. Spencer Jones 211
—— The law of error in the Greenwich variation of latitude observations, Harold Jeffreys 703
Lemaître, Georges, elected an Associate of the Society 537
Library, List of donors to, in 1938 415
—— List of exchanges 417
—— Periodicals purchased 423
Line Profiles : The Stark effect of hydrogen and centre-to-limb variations in the contours of $H\beta$, $H\gamma$ and $H\delta$, D. S. Evans 17
—— Stark effect in B stars, J. Stuart Foster and A. Vibert Douglas 150
—— Nova Herculis 1934: Contours and intensities of absorption and emission bands during the first three months of 1935, E. G. Williams 91
—— On the intensity of *Mg* 5183 in K-type stars, A. D. Thackeray 492
—— Note on the integration of the equation of the formation of absorption lines, H. R. Hulme 730
London, University of, Observatory and University College Observatory, Report of the proceedings of 347
Luyten, W. J., On the origin of the solar system 692

PAGE

Lyot, Bernard, The Gold Medal of the Society awarded him for his observations and photography of the solar corona in the absence of a total solar eclipse 140, 538
—— The study of the solar corona and prominences without eclipses (George Darwin Lecture, 1939) 538, 580
Lyttleton, R. A., On the rotations of the planets 181
—— On the fission of a rotating fluid mass 567

McMath-Hulbert Observatory, Films of moving prominences exhibited by Dr. H. D. Curtis at the ordinary meeting of the Society, 1938 Nov. 11 3
McMath, R. R., Motion pictures of small chromospheric flocculi 559
Magnetism, Terrestrial: The influence of the variability of the mean latitude of sunspots on the recurrence tendency of magnetic disturbances, G. H. Archenhold 723
Martin, E. G., Space reddening deduced from the moving cluster in Perseus ... 467
Melbourne Observatory, Report of the proceedings of 361
Meridian Astronomy, Some problems of, H. Spencer Jones (Presidential address) ... 424
Meteor Showers: The determination of meteor velocity from zenith attraction, Hideo Inouye 738
Michelson Interferometer Method, A modification of the, for the determination of stellar diameters, R. Fürth, K. Sitte and H. P. Appel 141
—— A modification of, for the determination of stellar diameters, P. Lacroute ... 733
—— On a proposed modification of Michelson's stellar interferometer, J. A. Carroll 735
Michie, C. B., Report of the New Zealand total solar eclipse expedition to Canton Island, 1937 June 8 132
Milburn, W., Micrometrical measures of double stars (30th series) 278
Mitchell, S. A., and C. A. Wirtanen, A comparison sequence for Nova Lacertæ 40

Nebulæ : The inclinations of the spiral nebulæ to the line of sight, F. G. Brown ... 14
—— A study of galactic rotation, based on the velocities of the planetary nebulæ, G. L. Camm 71
—— The distribution of the position-angles of the extra-galactic nebulæ in Horologium, F. G. Brown 534
Newbegin, A. M., Report of his observatory (Worthing) 365
Newton, H. W., A simple wedge-photometer for observing bright chromospheric eruptions with a spectrohelioscope 463
Novæ : see Stars, New.
Nutation, Constant of, The, Harold Jeffreys 206
—— The determination of the, from Greenwich latitude variations (Second paper), H. Spencer Jones 211

Obituary :—
List of Fellows and Associates deceased 297
Obituary Notices : Associates :—
Campbell, William Wallace 317
Donner, Anders Severin 321
Hale, George Ellery 322
Pickering, William Henry 328
Obituary Notices : Fellows :—
Armstrong, John Alexander 297
Barnacle, H. Glanville 298
Baume Pluvinel, A. de la 298
Baxandall, David 299
Brewitt-Taylor, C. H. 300
Brown, Ernest William 300
Consterdine, Reginald Henry 307
Cust, H. E. Purey 307
Davis, Percy L. H. 309
Evans, Joseph Edward 310
Goodacre, Walter 310
Howarth, Elijah 311
Pease, Francis G. 312
Punch, John William Robinson 312
Roberts, Alexander William 313
Williams, Arthur Stanley 313

PAGE

Observatories, Work at various: see reports of individual observatories (or observers) under their respective headings.
Occultations, Observations of, made at Teddington during 1937, J. L. Haughton ... 136
—— of stars by the moon observed at Melbourne Observatory in 1937, J. M. Baldwin 276
—— observed in 1938, Royal Observatory, Cape of Good Hope 471
—— of stars by the moon observed at Birmingham University during the year 1938, James Young 474
—— of stars by the moon, observed during the year 1938, Nizamiah Observatory, Hyderabad 575
—— observed at Teddington in 1938, J. L. Haughton 701
Officers and Council, 1939–40, List of 435
Öhman, Yngve, On some observations made with a modified Pickering polarigraph ... 624
Oort, J. H., Stellar Motions (Council report on the progress of astronomy) 369
Ottawa, Dominion Observatory, Report of the proceedings of the 351
Oxford, University Observatory, Report of the proceedings of the 348

Page, T. L., The continuous atomic absorption of light (Council report on the progress of astronomy) 385
Peek, B. M., Report of his observatory (Solihull) 366
Phillips, Rev. T. E. R., Report of his observatory (Headley) 366
Photography, Celestial: List of reproductions of celestial photographs by the Society 295
—— Increase in price of photographs on sale to Fellows 538
Physical Society, Joint Meeting with, to discuss " The Expanding Universe " 3
Planets, On the rotation of the, R. A. Lyttleton 181
Plaskett, H. H., The Oxford solar telescope and Hartmann tests of its performance ... 219
Plummer, H. C., Presidential address on presenting the Gold Medal of the Society to M. Bernard Lyot 538
Potter, Archdeacon Beresford, Fund 293
Presents announced 2, 59, 140, 437, 477, 538, 579
Pretoria, Radcliffe Observatory, Report of the proceedings of the 359
Progress and present state of the Society 281
Publications of the Society 296

Redman, R. O., A new projection micrometer machine for stellar spectrograms ... 686
Riverview College Observatory, N.S.W., Report of the proceedings of 362

Seismology: Seismological tables (Council report on the progress of astronomy), Harold Jeffreys 397
Sellers, F. J., Report of his observatory (Muswell Hill) 367
Sidmouth, Norman Lockyer Observatory, Report of the proceedings of the 350
Sitte, K., R. Fürth, and H. P. Appel, A modification of the Michelson interferometer method for the determination of stellar diameters 141
Smart, W. M., Determination of the constants of the velocity ellipsoid from radial speeds 61
—— The moving cluster in Taurus 168
—— —— Errata 535
—— The Ursa Major cluster 441
—— —— (Second Paper) 710
—— On the relation between the stream and ellipsoidal constants 561
—— A new member of the Ursa Major cluster 700
South Kensington, Imperial College Observatory, Report of the proceedings of the ... 347
Spectroscopy and Spectrophotometry: The Stark effect of hydrogen and centre-to-limb variations in the contours of $H\beta$, $H\gamma$ and $H\delta$, D. S. Evans 17
—— Nova Herculis 1934: contours and intensities of absorption and emission bands during the first three months of 1935, E. G. Williams 91
—— New measures of the wave-lengths of the calcium lines K and H, J. Evershed ... 121
—— Stark effect in B stars, J. Stuart Foster and A. Vibert Douglas 150
—— The continuous atomic absorption of light (Council report on the progress of astronomy), T. L. Page 385
—— On the intensity of *Mg* 5183 in K-type stars, A. D. Thackeray 492
Spencer, Herbert, Bequest 291

PAGE

Star Clusters : The moving cluster in Taurus, W. M. Smart 168
—— —— Errata 535
—— The Ursa Major cluster, W. M. Smart 441
—— —— (Second paper) 710
—— Space reddening deduced from the moving cluster in Perseus, E. G. Martin ... 467
—— A new member of the Ursa Major cluster, W. M. Smart 700
Stark Effect of hydrogen and centre-to-limb variations in the contours of $H\beta$, $H\gamma$ and $H\delta$, D. S. Evans 17
—— in B stars, J. Stuart Foster and A. Vibert Douglas 150
Stars, Diameters of : A modification of the Michelson interferometer method for the determination of stellar diameters, R. Fürth, K. Sitte and H. P. Appel 141
—— —— P. Lacroute 733
—— On a proposed modification of Michelson's stellar interferometer, J. A. Carroll 735
Stars, Distribution and Motions of : The "southern stream" and the *K*-term, P. Samuels Lall 42
—— Determination of the constants of the velocity ellipsoid from radial speeds, W. M. Smart 61
—— The moving cluster in Taurus, W. M. Smart 168
—— —— Errata 535
—— Stellar Motions (Council report on the progress of astronomy), J. H. Oort ... 369
—— —— (Second Paper), W. M. Smart 710
—— The Ursa Major cluster, W. M. Smart 441
—— Space reddening deduced from the moving cluster in Perseus, E. G. Martin ... 467
—— Stellar kinematics and mean parallaxes (Second paper), F. K. Edmondson ... 525
—— On the relation between the stream and ellipsoidal constants, W. M. Smart ... 561
—— A new member of the Ursa Major cluster, W. M. Smart 700
Stars, Double and Multiple : The fission of rotating bodies, K. E. Edgeworth ... 272
—— Micrometrical measures of double stars (30th series), W. Milburn 278
—— Council report on, in 1938, W. H. van den Bos 412
—— Apsidal motion in binary stars, T. E. Sterne 451
—— On the fission of a rotating fluid mass, R. A. Lyttleton 567
—— Apsidal motion in binary stars (I). II. Distributions of density. III. Limiting ratios of central to mean density, T. E. Sterne 451, 662, 670
—— Micrometrical measures of double stars, R. v. d. R. Woolley 742
Stars, New :
—— Nova Lacertæ, A comparison sequence for, S. A. Mitchell and C. A. Wirtanen ... 40
—— Nova Herculis 1934: Contours and intensities of absorption and emission bands during the first three months of 1935, E. G. Williams 91
—— Observations of novæ, 1938–1939, W. H. Steavenson 697
Stars, Parallaxes of : Stellar parallaxes determined at the Royal Observatory, Greenwich 49
—— —— Erratum 277
—— Stellar parallaxes determined at the Royal Observatory, Cape of Good Hope (Tenth list) 52
—— —— Errata 58
—— Stellar kinematics and mean parallaxes, F. K. Edmondson 525
Stars, Proper Motions of : The moving cluster in Taurus, W. M. Smart 168
—— —— Errata 535
—— The Ursa Major cluster, W. M. Smart 441
—— —— (Second paper) 710
—— A new member of the Ursa Major cluster, W. M. Smart 700
Stars, Structure of : Star models with variable polytropic index, Sir A. S. Eddington 4
—— On the density condensations of Cepheid variables, Z. Kopal 33
—— A theorem on the pressure in the interior of a star, W. Gleissberg 188
—— The theory of pressure ionization and the constitution of the white dwarf stars, F. C. Auluck 239
—— Remarks on the equilibrium of distorted polytropes, Z. Kopal 266
—— Collisions and the theory of radiative equilibrium, R. v. d. R. Woolley 478
—— The hydrogen content of white dwarf stars in relation to stellar evolution, Sir A. S. Eddington 595
—— The minimum central temperature of a gaseous star, S. Chandrasekhar ... 673
—— Note on the integration of the equation of the formation of absorption lines, H. R. Hulme 730

PAGE

Stars, Variable : On the density condensations of cepheid variables, Zdeněk Kopal 33
—— Twelve new southern variables, J. B. G. Turner 569
Steavenson, W. H., Report of his observatory (West Norwood) 367
—— Observations of novæ, 1938–1939 697
Sterne, T. E., Apsidal motion in binary stars 451
—— —— II. Distributions of density 662
—— —— III Limiting ratios of central to mean density 670
Stonyhurst College Observatory, Report of the proceedings of 351
Sun, Corona : Award of the Gold Medal of the Society to M. Bernard Lyot for his observations and photography of, in the absence of a solar eclipse ... 140, 538
Sun, Chromosphere and Prominences : Films of moving prominences made at the McMath-Hulbert Observatory, exhibited by Dr. H. D. Curtis 1938 Nov. 11 3
—— Council report on solar activity in 1938: Prominences, A. L. Narayan ... 410
—— Some hydrodynamical experiments in connection with prominences, H. Zanstra ... 499
—— The study of the solar corona and prominences without eclipses (George Darwin Lecture, 1939), Bernard Lyot 538, 580
—— Motion pictures of small chromospheric flocculi, R. R. McMath... 559
—— On the motion of solar prominences and streamers, H. R. Hulme 634
Sun, Eclipses of the :
—— 1937 June 8, Report of the New Zealand total solar eclipse expedition to Canton Island, C. B. Michie 132
Sun, Motion of the : The dependence of the solar velocity on the distance from the plane of the Milky Way, P. P. Bruna 248
Sun, Spectrum of the : Note on the Zeeman effect in sunspot spectra, J. Evershed 217
—— Measures of the relative shifts of the line 5250·218 and neighbouring lines in Mt. Wilson solar magnetic field spectra, J. Evershed 438
Sunspots and Faculæ : Note on the Zeeman effect in sunspot spectra, J. Evershed 217
—— Council report on solar activity in 1938: Sunspots, H. W. Newton 409
—— The influence of the variability of the mean latitude of sunspots on the recurrence tendency of magnetic disturbances, G. H. Archenhold 723
Sydney Observatory, Report of the proceedings of 362
Symms, L. S. T., H. R. Hulme and, The law of error and the combination of observations 642

Thackeray, A. D., On the intensity of *Mg* 5183 in K-type stars 492
Toronto, David Dunlap Observatory, Report of the proceedings of the 352
Treasurer's accounts for 1938 282
Trust Funds 293
Turner, J. B. G., Twelve new southern variables 569

Victoria, B.C., Dominion Astrophysical Observatory, Report of the proceedings of the ... 353

Wellington, N.Z., Dominion Observatory, Report of the proceedings of the 362
Wildt, Rupert, On the chemical nature of the colouration in Jupiter's cloud forms ... 616
Williams, A. Stanley, Bequest from the late 140
Williams, E. G., Nova Herculis 1934: Contours and intensities of absorption and emission bands during the first three months of 1935 91
Wirtanen, C. A., S. A. Mitchell and, A comparison sequence for Nova Lacertæ 40
Wolsingham Observatory, Report of the proceedings of 368
Woolley, R. v. d. R., Collisions and the theory of radiative equilibrium 478
—— Micrometrical measures of double stars 742

Young, James, Occultations of stars by the Moon observed at Birmingham University during the year 1938 474

Zanstra, H., Some hydrodynamical experiments in connection with prominences ... 499

20 IV '42 Library.

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ANNOUNCEMENT OF PROGRAMMES OF MEETINGS

Post-cards, giving as far as is practicable the programme of each Meeting, will be sent to those Fellows who inform the Assistant Secretary of their wish to receive them.

CONTENTS

Fellows elected 1

Candidates proposed ... ... *ib.*

Bequest from the late Dr. E. W. Brown 2

Presents announced ... ... *ib.*

Posthumous work of Dr. E. B. Baillaud ... ... *ib.*

Presentation of Artaut portrait of Sir William Herschel 3

Joint Meeting with the Physical Society ... ... *ib.*

Films of Moving Prominences ... ... *ib.*

Sir A. S. Eddington, Star Models with Variable Polytropic Index 4

F. G. Brown, The Inclinations of the Spiral Nebulæ to the Line of Sight ... 14

D. S. Evans, The Stark Effect of Hydrogen and Centre-to-Limb Variations in the Contours of $H\beta$, $H\gamma$, and $H\delta$ 17

Zdeněk Kopal, On the Density Condensations of Cepheid Variables ... 33

S. A. Mitchell and C. A. Wirtanen, A Comparison Sequence for Nova Lacertæ 40

P. Samuels Lall, The "Southern Stream" and the *K* Term 42

Royal Observatory, Greenwich, Stellar Parallaxes determined at the Royal Observatory, Greenwich 49

Royal Observatory, Cape of Good Hope, Stellar Parallaxes determined at the Royal Observatory, Cape of Good Hope (Tenth List) 52

Errata 58

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